The CLOSURE STRIP GUIDE

- An Analysis of
  Material Performance in
  Elastic, All-Weather Gasket Strips

BUILDING RUBBER DIVISION

ASPHALT CORPORATION OF AMERICA • DANVILLE, ILLINOIS

THE CLOSURE STRIP GUIDE
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Figure 1—Architect's Handy Guide to Identification and Physical Testing of Closure Strips

TEST	(NR) NATURAL RUBBER (SOLID)	(SBR) SYNTHETIC RUBBER (SOLID)	(CR) NEOPRENE (SOLID)[a]	OPEN-CELL RUBBER	CLOSED-CELL RUBBER	POLYETHYLENE FOAM[b]	POLYURETHANE FOAM[b]	VINYL FOAM[b]
1. IDENTIFICATION 1.1 ASTM-SAE designation	R	R	SC					PV(C)
1.2 Chemical type	**Natural Polyisoprene**	**Styrene Butadiene**	**Chloroprene**	**Sponge Rubber**	**Cellular Rubber**	**Polyethylene Foam**	**Polyurethano Foam**	**Cellular Polyvinyl Chloride**
1.3 Relative initial cost SBR = 100	115	100	125	80	84	98	46	95
1.4 Gen'l appearance	Black & colors—solid, dense rubber.	Black & colors—solid, dense rubber.	Black & colors—solid, dense rubber.	Black—large, uneven interconnecting cells; uniform pattern on two sides—when mfctd between fabric faced platens.	Black—small, uniform non-interconnecting cells—with or without thin skin on two sides.	White—large uneven cells—white waxy skin usually one side—light weight.	Dark grey—small, uniform cells—extremely light weight, thin-walled; scratchy surface—no skins.	Light grey—non-uniform cells—from large to small cells on skinned side; soft, skin-like feel; vinyl plasticizer smell.
1.5 Appearance of closure strip	Molded—uniform dimensions.	Molded—uniform dimensions.	Molded—uniform dimensions.	Die-cut, dished at ends, non-uniform dimensions.	Die-cut, dished at ends, non-uniform dimensions.	Die-cut, dished at ends, non-uniform dimensions.	Die-cut, dished at ends, non-uniform dimensions.	Die-cut, dished at ends, non-uniform dimensions.
1.6 "Rule of thumb" I.D. test	Burns—emits "rubbery" odor. Residue after burning is very tacky.	Burns. Pungent odor. Smoke contains small particles. Residue brittle and charred.	Sharp odor while burning. Copper wire in contact with burning surface gives green flame. Residue black ash.	Burns rapidly (see solid rubbers for type of rubber).	Burns (see solid rubbers for type of rubber).	Burns rapidly. Melts. Waxy smell.	Burns like "sparkler." Chars. Tacky, dripping hot residue.	Burns. Sharp chlorine odor. Acrid smoke.
				TYPICAL RESULTS				
2. STARTER TEST FOR CLOSURE FREEZING Directions: Place closure in water 24 hours—then freeze in freezer 24 hours—take out and flex.	Flexes easily.	Flexes easily.	Flexes easily.	May break cells or product.	May break cells or product.	May break cells or product.	May break cells or product.	May break cells or product.
3. SIMPLE WATER ABSORPTION TEST Directions: Leave strip in water four hours. Take out & squeeze.	No water absorbed.	No water absorbed.	No water absorbed.	Water comes out of cells.	Water comes out of cells.	Water comes out of cells.	Much water comes out.	Water comes out of cells.
4. ELEMENTARY COMPRESSION SET TEST Directions: Place closure strip on hot radiator overnite with unabridged dictionary on top of it.	Recovers original shape easily.	Recovers original shape easily.	Recovers original shape easily.	Little recovery. Permanent set.	Little recovery. Permanent set.	Little recovery. Permanent set.	Little recovery. Permanent set.	Little recovery. Permanent set.
5. PRIMARY FLAMMABILITY TEST Directions: Hold closure with knife or fork. Light fire to it over sink. Count slowly. Note smell and how it burns.	Burns (see above).	Burns (see above).	Almost self-extinguishing.	Burns easily (see above).	Burns easily (see above).	Burns easily (see above).	Burns easily (see above).	Should not support flame (see above).
6. WAY OF ESTIMATING TENSILE STRENGTH Directions: Put one end of closure strip in vise. Mark length. Stretch. Mark length when it breaks.	Good tensile strength.	Good tensile strength.	Good tensile strength.	Poor tensile strength.	Poor tensile strength.	Poor tensile strength.	Poor tensile strength.	Poor tensile strength.
7. AN APPROACH TO WEATHERING Directions: 7.1 Measure closure strip's length. See & note how far pencil point sinks into it—using book as weight. Weigh strip on postage meter.								
7.2 Leave strip on window sill for one month. Repeat 7.1.	Very slight or no effect on: hardness, dimensions, weight.	Very slight or no effect on: hardness, dimensions, weight.	Very slight or no effect on: hardness, dimensions, weight.	Differences after weathering: harder, shorter, loss of weight.	Differences after weathering: harder, shorter, loss of weight.	Differences after weathering: harder, shorter, loss of weight.	Little differences after weathering: somewhat harder, dimensional change, some weight loss.	Differences after weathering: harder, shorter, loss of weight.
7.3 Repeat for six month period.	Very slight or no effect on: hardness, dimensions, weight.	Very slight or no effect on: hardness, dimensions, weight.	Very slight or no effect on: hardness, dimensions, weight.	Effects more pronounced.	Effects more pronounced.	Effects more pronounced.	Effects more pronounced.	Effects more pronounced.

[a] Neoprene is the generic name for all synthetic rubbers of chloroprene. Contrary to some opinion, all rubber is not neoprene. Neoprene is currently of third importance among many synthetic rubbers used. For purposes of this study, neoprene is considered one of the "rubber" group.

[b] Cellular Plastics—consisting of mixtures of closed-cell and open-cell "foam" or "sponge."

BUILDING RUBBER DIVISION
ASPHALT CORPORATION OF AMERICA

THE CLOSURE STRIP GUIDE

AN ANALYSIS OF MATERIAL PERFORMANCES IN ELASTIC, ALL-WEATHER, GASKET STRIPS

BY

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CHICAGO, ILLINOIS ● MAY 1963

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ABSTRACT

The flexible gasket strip used to seal corrugated or ribbed siding and roofing to its flat framework—at footings, doors and windows, eaves and ridge—is known as a closure or filler strip. Even though often representing less than 5% of corrugated roofing or siding installation costs, with today's architects and consumer demands for tighter buildings, the failure of this strip (leaks) can cost hundreds of dollars for call backs.

In the past few years numerous types of flexible materials have been used as closure strips, oftentimes without regard to their performance, once installed. Specifically, many types of sponge (cellular) closure strips—both plastic and rubber—used because of their flexibility, extreme lightness, and initial low cost—have been the source of leaky, loose construction. Examples of the consequences of their failure have become legion in the building trades.

For example, a relatively new Air Force hangar built of corrugated asbestos-cement was converted to staff offices. The first winter the building was drafty, hard to heat, and extremely uncomfortable. Maintenance men found the plastic closures, used by the erector, had shrunk and fallen out. A large power plant discovered its buildings leaking water after only six months. The leaks were due to a type of plastic cellular closure which had melted. An erector in New England, one winter morning was surprised to find his men couldn't handle their sponge closures without breaking them. The ostensibly water-resistant, closed-cell rubber closure strips had absorbed water and frozen. During a rainstorm, a large brewery discovered water coming down on top of its pasteurization tanks from a roof-full of newly-installed plastic skylighting. The brewery's construction department forced the erector to take off every sheet and replace all the closure strips. This disclosed that the cellular rubber strip had taken a permanent set on being fastened down. When high winds, accompanying the rainstorm pulled at the plastic skylighting, the closure strip hadn't recovered enough to seal the gaps.

Over the years, a set of performance requirements on the closure strip has grown up piecemeal. This study, in interviews with architects, manufacturers of corrugated materials, erectors, and industrial users, sets forth these requirements; measures commercially available strips according to these requirements; and, then, suggests a sample performance specification for an all-weather closure strip.

Briefly, these requirements can be listed under eleven headings:

Weathering
Aging
Cold
Flammability
Thermal Conductivity
Water Resistance
Compression-Deflection
Tensile Strength
Hardness
Compression Set
Dimensional Requirements

The job of sealing the corrugated or ribbed building panel to its framing is two-fold. It requires a good quality, rubber-washered, sheeting fastener and an all-weather closure strip. The two are interdependent. As with the closure strip, the principle cause of fastener leaks is deterioration or weathering of the rubber (washer). The performance of the flexible closure material used to gasket the corrugated building panel, is most important. Placed in ridges, eaves, gable ends, corners, and windows, doors, and footings, the closure strip is of strategic importance to the tightness of the structure.

The study found three types of rubber closure strips commercially available—soft, solid rubber; open-celled rubber; and closed-cell rubber—and three types of plastic—polyethylene foam, polyurethane foam, and polyvinyl chloride foam. Two plastic foam strips and one cellular rubber strip were called "closed-cell" sponge (their cells were predominantly non-interconnecting).

To aid architect and purchasing agent in identifying various types of closure strips, a glance at Figure 1* is recommended. Figure 1 also brings together a few simple tests, which can be performed in office or at home, and which may reveal a strip's capacity to perform its job. All tests, of course, can be validated in the reader's laboratory or samples may be sent to a commercial laboratory for confirmation.

Comparative independent laboratory tests, made of the six types of closure strips above, revealed that dimensional and physical requirements of an all-weather closure strip were met only by soft, solid, dense rubber strips. Thus, cellular closures, both open and closed-cell, failed dimensionally and, in most respects, were physically unqualified for the engineering and architectural requirements of a closure. Closures of cellular materials (sponge, foam, and expanded), in general, but in varying degree, shrank dimensionally, absorbed water, failed aging tests, and were permanently deformed under compression.

The pages to follow will unfold complete definition of the closure strip, its importance, functions, and the types of strips available. What is required of a closure is brought out in detail and a comparison made of commercially available strips. Finally, from the findings of the study, a sample specification is offered. It is hoped this study may have permanent usefulness as a reference to closure strips and aid architect and buyer in avoiding costly mistakes in specifying the closure strip.

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*Inside Front Cover.

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Chicago, Illinois
May, 1963

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I. INTRODUCTION

Definition of a Closure Strip

The closure strip is an elastic, gasket strip, normally corrugated on one side and flat on the other, providing the sealing and transition function between the corrugated shape of the roofing or siding sheet and its flat framing member. Plate I shows a closure in place – sealing translucent plastic paneling.

Importance of the Closure Strip

No one knows better than the architect the importance of and attention to the performance in use of certain low cost, but strategically placed items commonly used in building construction. Two of these items, in corrugated construction, are fasteners and closures. Together, it is estimated, they represent less than 5% of the roofing and siding installation costs. But, nothing eats up builder profit or ruins architectural reputations faster than skimping on the quality of either accessory.

Call backs, which usually result from improperly installed fasteners or poor quality closure strips–are a costly proposition. For example, a large manufacturer of coated aluminum installed a sponge closure strip to seal translucent plastic paneling. The panel was used as continuous lighting to the eaveline of the plant's brick walls. The installation was apparently all right for the first three years. Then, the union steward complained of poor heating and drafts in several areas. Heating and blower systems were thoroughly examined. But, it was not until a spray booth failed to draw properly, that the maintenance department checked outside the plant. All fasteners were holding well, but the closure strips had shrunk, and had set to the shape they were first squeezed in fastening. The wall and panel had moved slightly leaving large voids. And, in some cases, the closure had started to disintegrate.

At two closures per sheet (top and bottom of the sheet), the initial cost-savings over solid rubber closures was 8¢. The plant manager estimated the cost per sheet of replacing the closures at 150 to 200 times more than the original eight cents saved. Unfortunately, the man who was blamed was the architect.

Function of the Closure

In the use of corrugated panels for external sheeting–whether the panels be of metal, asbestos-cement, plastic or glass, the performance of the closure strip is vital. It seals, insulates, flashes, and gaskets all openings where the corrugated or ribbed panel meets a flat weather-exposed surface. The strip is used to "weather-tight" and close the gap between the corrugated or ribbed building panel and its structural framing. Architectural details, taken from a variety of plans on recommended uses of closure strips, are found in Figure 2.

Types of Closure Strips

Oakum rope caulking was used to close corrugated sheeting in the first applications of this product to building construction. Subsequently, a preformed bitumen strip was developed. The latter, an asphalt composition strip, has gradually been replaced by the more rubber-like materials found on the market today.

This survey found the following materials used in closure strips:[1]

Asphalt and asbestos composition
Asphalt and cork composition
Glazing putty or caulk
Lead
*Polyethylene-foam[2] [4]
*Polyurethane-sponge foam[2] [3]
Polysulfide caulking
*Rubber–solid, sponge,[3] and expanded foam[4]
Sheet metal
*Vinyl–foam[2] [4]
Wood

---

[1] *Designates closures included in this study. Those materials not studied were eliminated because: (1) they were sometimes called a "make-shift substitute" for the closure by erectors interviewed; (2) they were not widely used; and, or (3) they were not commonly considered to have an elastic behavior—a function considered basic to a closure strip's performance.

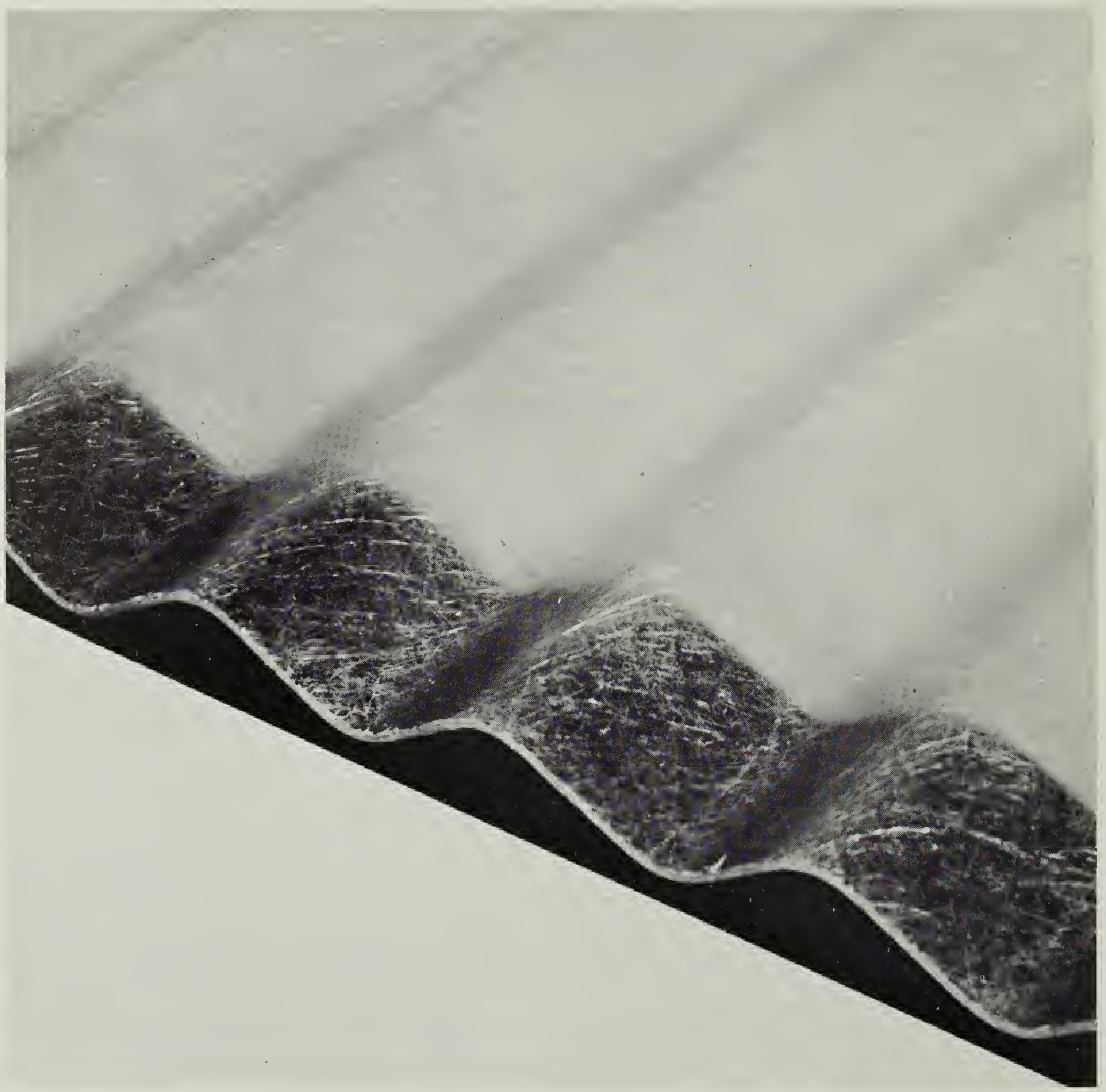
[2] Also known as "cellular plastic—a plastic whose density is decreased substantially by the presence of numerous cells disposed throughout its mass." Cf. Alan F. Randolph (ed.), *Plastics Engineering Handbook of the Society of The Plastics Industry, Inc.* (3d ed.; New York: Reinhold Publishing Corp., 1960), p.xxxvi.

[3] Open-cell cellular rubber and plastics. Technically, open-cell products are considered synonomus to sponge. Expanded foams (closed-cell) are supposedly composed of predominantly non-interconnected cells. In describing cellular closure strips this study has used the terms "sponge," "cellular," and "foam" interchangeably.

[4] Closed-cell (expanded foam) rubbers and plastics. Cf. ASTM D-1056-59T. *1961 Book of ASTM Standards* (Philadelphia: American Society for Testing and Materials, 1962), Part 11, p. 477ff.

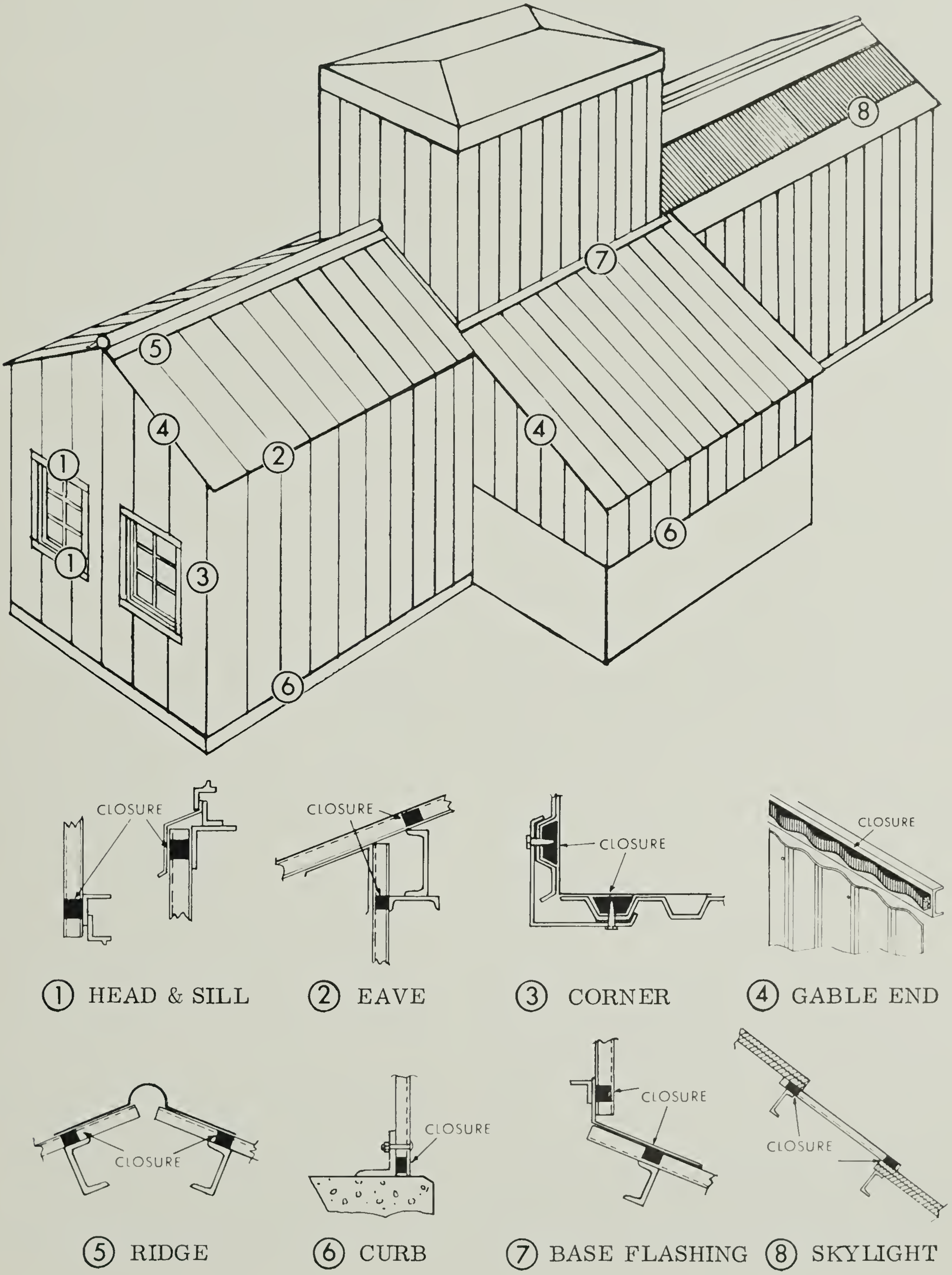
PLATE I

Picture of a Closure Strip in Place



Example: Sealing Corrugated Plastic Paneling

Figure 2—Applications and Architectural Details of Closure Strip Installations in Building



Purpose of This Study

Thus, it is the primary purpose of this study to define and clarify architectural and engineering requirements for the preformed, elastic gasket strip used with corrugated and ribbed building sheets, commonly known as a closure or filler strip.

Secondly, from a laboratory and field comparison of the performance characteristics of these strips, the study proposes to draw a sample specification for the closure strip.

Scope and Methodology

This study covers the physical and dimensional requirements of a closure strip in various applications and includes an appraisal of commercially available strips. A comprehensive statement of both physical and dimensional requirements for closure strips was prepared after thorough study of the architectural systems used with corrugated and ribbed building materials.

Samples of commercially available products were then purchased on the open market and tested by an independent materials testing laboratory to determine conformance to these requirements. From this, and a field examination of the use of closures in corrugated and ribbed roofing and siding systems, recommended specifications for the closure strip were formulated.

II. REQUIREMENTS OF A CLOSURE STRIP

The wide variety of rubbers, plastics, and other materials available today, and the wide variability of their performance in use, made it vitally important that the right material be selected for this particular application. Corrugated or ribbed sheeting, with the easy installation of the closure strip, has appealed to architects and contractors because of its simplicity and economy. With all its advantage, however, this type of construction has presented a problem of sealing the corrugated or ribbed panel ends. Thus, in considering the appropriate closure material, an understanding of the minimum physical properties required is essential.

As the architectural details, (Figure 2), have indicated, applications of the closure strip were found from a building's ridge to its footings.[5] In many of the applications illustrated, the closure would be exposed to wind-driven rain and dust, to ice, to high roof temperatures and sunlight, and to building expansion and contraction movement as well. The latter involves dynamic contact with the various corrugated and ribbed materials of buildings and their framing. Conditions of exposure for the closure, again depending upon its location in the building, and the location of the structure itself, would vary from mild to severe. Lacking these definitions, the study assumed the physicals required were those for an all-weather closure strip.

From this assumption the closure must meet two major requirements—physical and dimensional. What is required of the closure physically depends on the environment it is placed in and the function it is to perform.

Physical Requirements of a Closure Strip

Environmental Exposure Requirements

Heat—According to authorities,[*] heat buildup on roofing materials might approximate 50% greater than surrounding recorded air temperatures, depending upon the season of the year. Thus, for an all-weather closure, a heat-aging requirement would be mandatory.

The presumed effects of heat on the aging of an elastomer[6] or plastic[7] can be somewhat duplicated in the laboratory, by what are described as "accelerated" aging tests. However, a note of caution should be made. Correlation of results between accelerated and natural aging is difficult in many cases. Accelerated tests do, however, show trends and are widely used as a guide. Procedure for these tests are described in ASTM designation D-573, and D-865.

Cold.—The closure strip subjected to freezing northern climates may fail in service by being too stiff to function in its intended manner, that is, to possess sufficient resiliency to continue to flex and recover with structural movement. Prior to installation also, the strip should be suitable for nailing or fastening without shattering under impact (before its brittleness temperature has been reached).

The brittleness temperature is a fixed property for each type of polymer[8] used as a closure material, subject to some modification by the type of plasticizers compounded into the material. The laboratory tests as outlined in ASTM procedure D-746 cover this property.

Flammability.—The distinction between definition of heat resistance and flame or fire resistance (resistance to flammability) is important. The former has no connection with burning, merely the aging properties at elevated temperatures. Flame or fire resistance means the resistance to actual burning.

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[5] Cf. Figure 2, p. 3.

[*] This and other statements made on common practices on the manufacture and erection of corrugated building panels were the results of interviews conducted by the author, January-August, 1962.

[6] An elastomer is a material which at room temperature can be stretched to at least twice its original length and, upon immediate release of the stress, will return with force to its approximate original length. Literally an elastic part or elastic polymer. Certain rubber compounds and very little else, meet this requirement.

[7] A plastic is a material that contains as an essential element an organic substance of large molecular weight, is solid in its finished state, and, at some stage in its manufacture or its processing into finished articles, can be shaped by flow. Rubber can thus be classed as a plastic. The difference between rubber and most other plastics is that the molecular chain in the plastic when stretched and partly oriented, will retain its configuration after the extension force is released. The rubber chain retracts once force is released (or it has elastic behavior).

[8] A polymer is any compound formed by two or more molecules into another compound having the same elements in the same proportions, but a higher molecular weight and different physical properties. The compound formed has a large number of repeating giant molecular units. Hence "poly" from the Greek, many, and "meros," parts. Fibers, rubbers, plastics are all classed as polymers.

First, it should be understood that all organic materials—elastomers and plastics—will burn. For example, since neoprene (a chloroprene elastomer) contains a high portion of chlorine it is normally thought of as being flame or fire resistant. This is a relative term, however. Compared with wood for example, which burns well, it is fire resistant. Nevertheless, not all neoprene can be classed as flame resistant. Special compounding can be done by the manufacturer to make neoprene flame resistant. It will still burn, but at a flame-spread rate considered relatively slow.

Next, turning to the closure and its function. Solid rubber closures have been used in fireproof, semi-fireproof, and heavy timber buildings throughout the United States. Even though they are slow-burning or self-extinguishing, their relatively small volume in a building compared with other materials of construction, and their usual installation with surrounding flame resistant materials, make them a relatively non-contributing material to any fire. However, in the interest of full knowledge, it is felt the study should examine the flame-spread rating of present commercial closures and define safety limits. It is suggested that plastics be examined according to ASTM-D-635 and elastomers by MIL-STD-417 (ORD), suffix M.

Ozone.—Ozone is the component known to be responsible for cracking or cutting of stretched elastomers and plastics. Ozone, even in dilute concentrations, may render some closure strips useless as gasketing in a very short period. The tentative test method for estimating relative resistance of a closure material cracking, is described by ASTM D-1149. Again, the test cannot be expected to correlate wholly with outdoor exposure tests, since the latter tests the effect of light oxidation with water leeching, and in variations of temperature in ozone concentrations.

Describing a closure strip as "weather resistant" implies that a material will withstand prolonged outdoor exposure to the elements without deteriorating to a point where it is no longer fit for service. Outdoor exposure on the roof of a plant, or lab, can readily show the effects of weathering on inadequately protected closure strips. ASTM D-1171 describes the methods for comparing and mounting samples for such a test.

Possibly more indicative of actual service conditions encountered by the closure, is a test of a closure's resistance to the freezing-thawing cycle. Closures may be frozen in ice, or ice-clad, melted, and re-frozen in weather-exposed installations such as gutters, eaves, etc., many times during a normal winter.

The freezing-thawing cycle test proposed, was adopted at the suggestion of staff members associated with the Permafrost Laboratories, U. S. Army Corps of Engineers, after a series of tests devoted to estimating the closure's performance in "Dew-Line" projects. It was felt that, particularly in gutter installations, this test would most nearly simulate environmental and climatic conditions encountered by the closure in Northern exposures. The test, in its simple elements, consists of: 1) immersing the closure in a water-filled tray; 2) freezing the tray and closures; 3) unfreezing the tray and closure; and 4) exposing the closure to a sunlamp until touch-dry. This is repeated three hundred times—an estimated number of freeze-thaw cycles for Northern climates in a fifteen year period.[9]

Thermal Insulation.—The material used to help retain heat where it is wanted or excluded it from areas rates as "thermal insulation." No substance is an absolute heat stop, as there will always be some transfer of heat. Any solid material will retard the flow of heat if it is sufficiently air-tight. In this respect, dense materials are generally less "efficient" than materials with voids.

The closure functions as an insulating material, but in a very minor capacity. Some insulating value might be helpful but not a primary function.

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[9] This figure was arrived at through an estimate of ground thaw occurring in the Middle West states. It is not simply the number of times the temperature goes past 32°F. Actually, ice on buildings may soften two to three times per 24 hour winter day. A complete run-off or melt, however—depending on the structure's height, locality, etc.—was considered comparable to ground thaw. Cf. National Research Council, National Academy of Science, Highway Research Board, *Special Report 61-E*, p. 8. These tests, conducted in Ottawa, Illinois during winters of 1958-59, 1959-60, and 1960-61 found soils surrounding paving thawed from 5-10 times per winter. Therefore, a material designed for 15-20 thaws per winter would appear to account for the majority of freeze-thaw cycles, as defined. Of course, the variations could be as large as the figures themselves.

A measurement of the insulation value of a material is known as its thermal conductivity. Defined, it is "conductivity measured in British thermal units transmitted per hour per square foot of material one-inch thick per degree Fahrenheit difference in the temperature of the two faces."[10] ASTM C-177 outlines a method of measurement of this characteristic.

Water.—Highly water absorbant closures on gutters installations have been known to "wick" water into otherwise tight structures. In cold weather erection, closures have been broken by handling before installation because water absorbed by them has frozen. Northern freezing-thawing cycles break down many materials rapidly. Furthermore, moisture content of the closure strip is very intimately related to such physical properties as it's mechanical strength and dimension. To determine the comparative ability of the material to withstand the effect of water, ASTM designation D-471 or Federal Test Method Standard 601, Method 6611 may be used.

Dynamic Requirements of the Closure Strip

The closure strip's function has been determined as that of an all-weather gasket to structurally seal buildings using corrugated or ribbed roofing or siding materials. To outward appearances, the strip fastened down under the sheet is simply an inert filler. But with variations in temperature, settling of the materials of building, and expansion and contraction of the sheeting to which it is applied, the closure undergoes many types of dynamics. It does bear a load. It should flex and stretch with the structure's movement, and be soft enough to conform to irregularities. And to be a true gasket, the closure strip needs to recover after compression.

Compression-deflection.—The compression-deflection value is defined as the weight in pounds per square inch required to compress a material to a given percentage of its original thickness. Thus, the compression-deflection value is an indication of load-carrying ability (ASTM D-575).

While some of the corrugated building materials are moderately light (e.g. corrugated aluminum siding averages .414-.918 lbs. per sq. ft. and plastic .50 lbs. per sq. ft.)[11], others are extremely heavy (e.g. steel, 1.5-3.0 lbs. per sq. ft.; asbestos, 3.5-4.7 lbs. per sq. ft.). Thus, in ordinary roofing installations, the load bearing function of the closure, for even the lightest roofing, becomes critical.

Tensile.—Tensile properties are widely used as a rapid means of measuring quality. The tensile or mechanical strength requirement (ASTM D-412) of the closure strip would be quite low in comparison with other elastomeric compounds.

Elongation.—The ability of the closure to stretch without breaking is also a desirable property in the strip. This stretchability of an elastomer is called "elongation" in test terms (ASTM D-412). And, as important from the standpoint of its service as a gasket seal in a building experiencing settling, expansion, and contraction, was the closure's ability to recover.

Hardness.—Corrugated siding and roofing panels were admitted by most sheet manufacturers to be, at best, "imperfect" according to metal working standards. The very nature of the process of forming the corrugations or rib resulted in variations in the formed sheet.[12]

Thus, it was assumed that "softer" closures would be helpful in sealing the irregularities of a corrugated or ribbed sheet.*

Compression Set.—All buildings, but particularly those made of corrugated and ribbed siding and roofing sheets, experience movement. The siding or roofing sheet moves with building settlement, winds, heat, and cold. The closure must maintain a flexing seal with this movement —performing dynamic stressing.

By movement, this study does not mean to imply that all buildings possess the famed movements of the tower of the Empire State Building or Seattle's Space Needle. Given specified foot-

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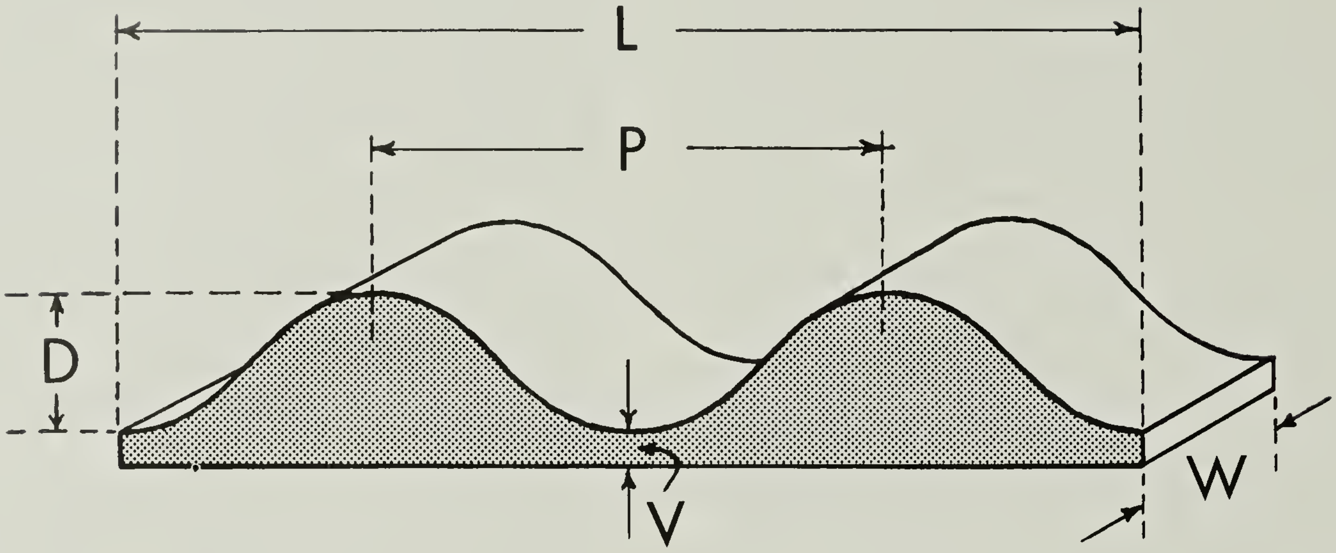
[10] Allen C. Wilson, *Industrial Thermal Insulation* (New York: McGraw-Hill Book Co., 1957), p. 257.

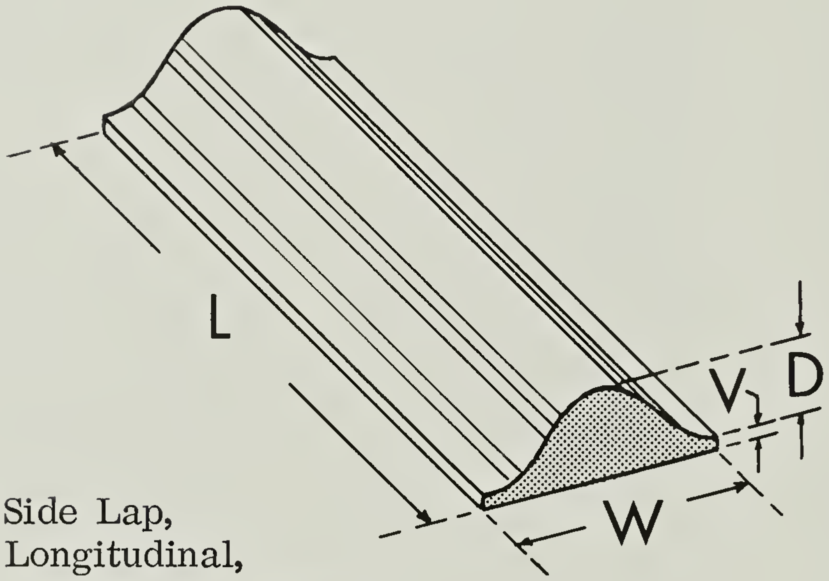
[11] Robert Berne (ed.), *1962 Building Products Register, AIA* (2d ed.; Washington, D. C.: American Institute of Architects, 1961), pp. 147-155.

[12] In metal forming, for example, rolls and corrugators experienced heavy wear. And, variations in strengths of mill sheet runs often meant wide variations in the springback of ostensibly the same material after forming.

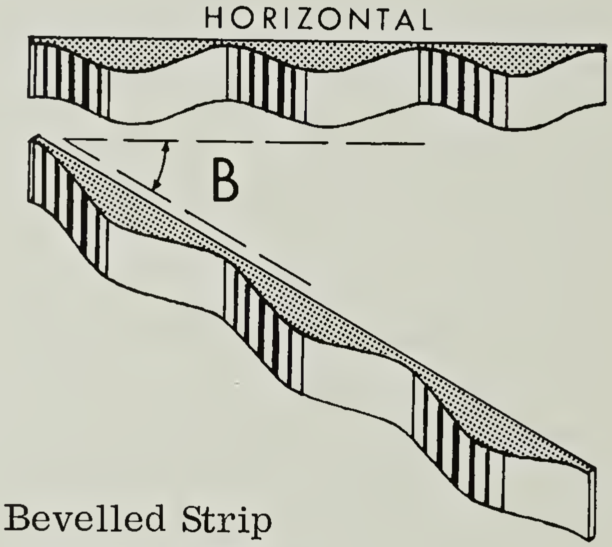
*Cf. ASTM Designations D314-52T, D531-49, and D676-55T.

Figure 3—Nomenclature of the Closure Strip





Side Lap,
Longitudinal,
or Vertical Closure.



Bevelled Strip
compared with
Horizontal Strip

P — PITCH (or width of corrugation) is the measurement from center to center of adjacent corrugations.

D — DEPTH is the measurement from peak of corrugation to inside of valley.

W — WIDTH is the thickness of the closure strip from side to side.

L — LENGTH is the measurement of the closure strip from end to end.

V — VALLEY (or web) is the measurement from flat side of bottom of material to low point in valley.

B — BEVEL is the slant of the closure's corrugations to the horizontal as determined by the inches rise in foot run of the roof in relation to the horizontal at the gable end.

ings, the continuous rigid frame steel structure —walled or roofed with corrugated sheets,—has little movement overall. This, again, is assuming adequate beams, tie rods, knees, etc. from the structural engineer's calculation of deflection, shear, distortion, and strain of these members under a full live load.[13]

However, movement is significant for the closure. The movement of corrugated sheet structure will depend on such factors as the height of the building, differences in temperature of the ground and air, how much heat is in the building,[14] the length of the building and type of existing structure it may be attached to,[15] and other factors. In addition, wind, ice and snow will affect this movement, however slight.

The materials used in corrugated sheeting—steel, aluminum, asbestos-cement, glass and plastics—all vary in their coefficients of thermal expansion. The corrugated sheet itself will act much like an accordion—from the nature of its shape.[16] The closure must distort and recover with these movements to perform as a compression seal and continuously gasket the corrugated sheet and its framing.

The ability of a closure to retain these elastic properties, on being compressed by the fastened down corrugated roofing or siding sheet, and recovering with building movement, is usually measured by compression set tests. For purposes of this investigation, a single compression set requirement was made of the closure. The measurement of the residual decrease in thickness of the closure after a loading device had been applied (ASTM D-395) indicated whether the closure would recover and provide a continuous seal.

Dimensional Requirements of a Closure Strip

Length[17]

The length of a closure was found to be dictated by the cover width of the corrugated or ribbed building panel. Larger, longer strips were unsatisfactory because they did not effectively seal non-uniform stretching or contraction of the building panel erected over a large area.[18] Smaller strips demanded frequent mastic applications and often left gaps at their joining.

Strips, made to the cover width of the building panel, were jointed or butted underneath the laps of adjacent panels, and appeared to do an effective job. Also, sheeting and framing movement at the lap joint, compressing or stretching the closure, was kept flashed in all instances where the closure did not shrink.

Width[17]

According to architects, manufacturers of sheeting, and erectors, the required width of the closure strip was determined by the fastening system used, the location of the closure strip on the building, and the design of auxiliary metal flashing employed, if any.

Diameter and type of fastener would naturally affect this dimension. The wider diameter screws and bolts dictated wider closure strips.

The exposure factor, as determined by the location and expected performance of the closure, also had a bearing on this dimension. For example, it was found that gutter installations with possibilities of seasonal submergence in water, normally required wider widths of closures (from 1¼ inch to 2 inches). Finally, where auxiliary metal flashing was used, closures down to ½ inch wide were found in field installations.

Pitch and Depth of Configuration[17]

The center to center measurement of the ribbed or corrugated sheet and its depth, determined the pitch and depth of the closure.

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[13] Cf. Martin P. Korn, *Steel Rigid Frames Manual, Design and Construction* (Ann Arbor: J. W. Edwards, Inc., 1953), p. 50ff.

[14] For example, an open shed-type structure, such as freight shed for a railroad, will have high roof temperatures from exhaust smoke, and be very cold near the ground.

[15] A particularly long rigid frame, metal-clad building, for example 1000 ft. in length, attached to an existing stone structure may have to have several expansion joints. Rule of thumb is to provide for an expansion joint every 300 feet—allowing ± 1 in. contraction or expansion at the mean temperature of between -20°F to 115°F.

[16] It is well known that corrugated sheets often "grow" in width with field handling.

[17] Figure 3, p. 8.

[18] For example, an erector, interviewed, stated that metal clad buildings were sheeted one panel at a time. Single panels with their closure strips were often stretched or pulled together to come out just right in purlins, eaves, gable ends, or corners.

Subsequent testing discovered these dimensions to be quite critical in the closure's ability to gasket sheeting.

Thickness of the Valley[17]

The thinnest portion of the closure was customarily called "the web" or valley. Structural engineers were of the opinion that this dimension should be kept as thin as possible, taking into consideration that extremely thin sections of some materials might not be dynamically tolerated. In general, this dimension varied between ⅛ inch and ½ inch.

Summary

Exposed to elements and in dynamic contact with materials of corrugated construction, the closure has both physical and dimensional requirements peculiar to its function as a closure strip.

Installed, in its environment, high roof temperatures age closure materials quickly. In addition, the closure must be able to endure low temperatures, freezing-thawing cycles, and, further, be non-water absorbent. Finally, it must function as a thermal insulator and be slow-burning or, at least, non-contributory to flaming of adjacent materials.

Dynamically, the closure strip does bear a load (compression-deflection), should flex and stretch with structural movement (tensile and elongation), and yet be soft enough to conform to supposedly uniform, but, in practice, irregularly shaped materials. Most important is the closure strip's ability to be squeezed down, recover, be compressed and recover again with its complementary materials (compression set). Specific tests, using American Society of Testing Materials' standards, were set up to measure the above required qualities.

Dimensionally, the closure strip needs to conform to its corrugated or ribbed sheeting, taking into account the service required of it. It was in the dimensions of competitive closure strips that differences were first observed. Initial study was thus devoted to finding the basis for this difference.

III. COMPARISON OF MATERIALS USED IN COMMERCIALLY AVAILABLE CLOSURE STRIPS

Dimensional Features

Possibly nowhere in this study were the differences between materials more surprising than in the comparison of the physical dimensions of closure strips upon receipt. Table 1 compares the lengths of several types of closures, manufactured in different materials, on their receipt from manufacturers or distributors.

Some explanation of the variance in length could possibly be explained by loose manufacturing tolerances or careless workmanship.[19] Others might be due to a variety of reasons. Aging and shrinkage of purportedly new cellular material appeared most obvious. Yet, the closures purchased were presumably from "fresh" stock. Since the data of this table hinted of uncontrollable variations in dimensional properties of sponge (cellular) closures, a fifteen-month weathering test was devised to examine possible dimensional instability in all cellular type closures.

The Weathering Test

The closure strips studied[20] were placed in a six-foot square, open-topped, wooden box with six-inch high sides, which was attached to a testing rack—inclined forty-five degrees to the horizontal with open exposure to due South. The rack was on a roof of a laboratory storage building, approximately fifteen feet above ground level located in central Illinois.

The strips were placed in the box on February 27, 1961 and removed on May 31, 1962. No effort was made to mount or fasten down the closures.[21] An expanded steel grating was placed over the sides of the box to keep lighter strips from being blown out. Approximately

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[19] In this respect, it was noted that two solid rubber strips, acquired from two different manufacturers, ran from 1/8 inch to 3/16 inch over their nominal length, but held this dimension throughout the test.

[20] Cf. p. 1.

[21] Contrast with ASTM D-1171

TABLE 1

COMPARISON OF LENGTHS OF VARIOUS CLOSURE STRIPS AS ADVERTISED AND AS RECEIVED[a]

Closure Strip (By Type of Elastomer or Plastic)	Configuration (Pitch and Depth of Corrugation)	Length (As Advertised in Manufacturer's Literature)	Length (As Received Unaged)
Rubber—solid	2.67″ x 7/8″	28″	28″
Rubber—open cell	2.67″ x 7/8″	28″	27 1/4 ″
Rubber—closed cell[b]	2.67″ x 7/8″	28″	27 11/16″
Rubber—solid	4″ x 1″	32″	32 1/8 ″
Polyethylene Foam	4″ x 1″	32″	31 7/8 ″
Polyethylene Foam	4″ x 1″	32″	31 1/2 ″
Rubber—solid	4.2 ″ x 1 1/16″	37 3/4″	37 3/4 ″
Polyurethane Foam	4.2 ″ x 1 1/16″	37 3/4″	37 1/2 ″
Polyurethane Foam	4.2 ″ x 1 1/16″	37 3/4″	37 1/2 ″
Vinyl Foam	4.2 ″ x 1 1/16″	37 3/4″	35 7/8 ″

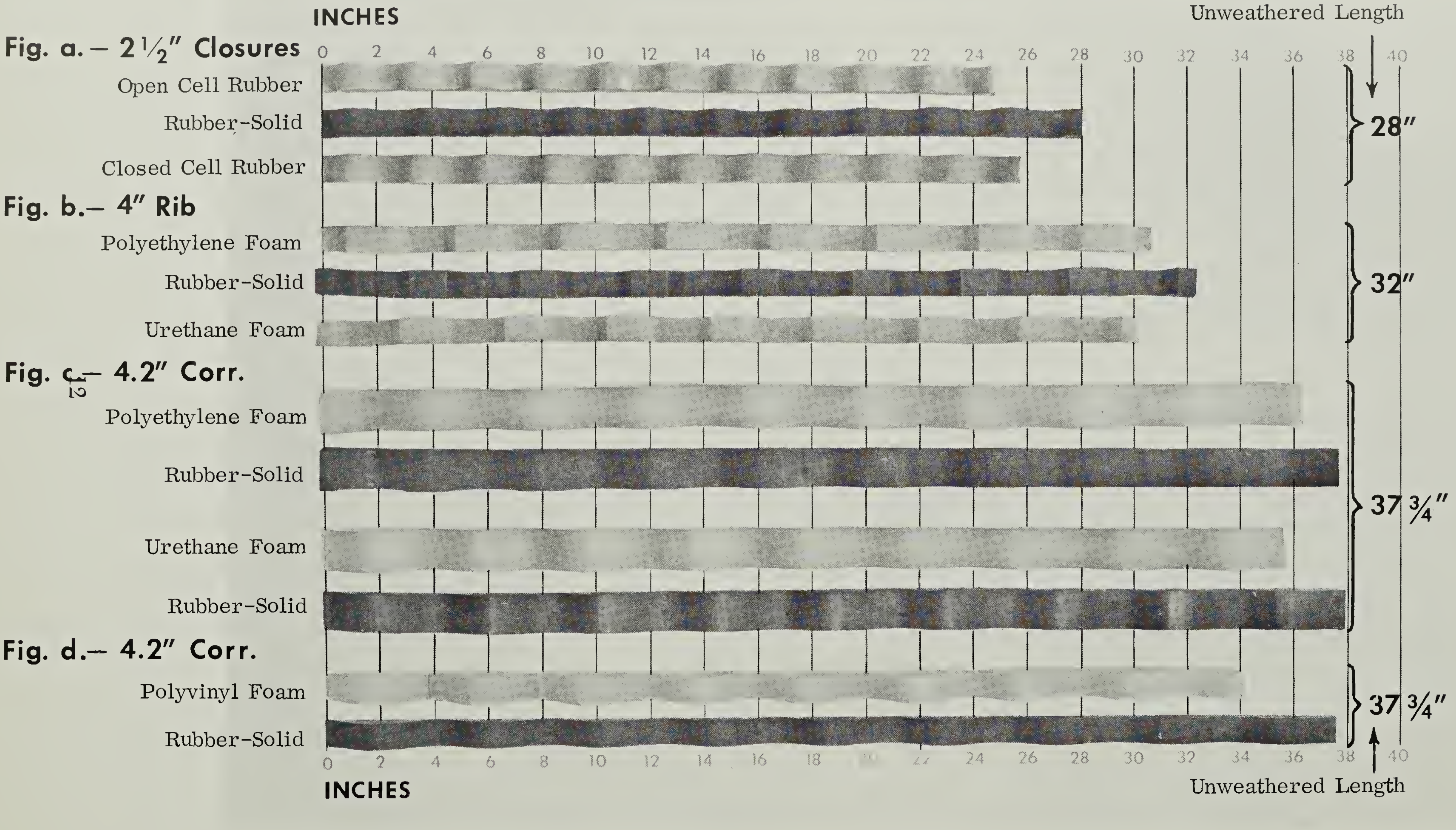
[a] Lengths as advertised in manufacturer's literature as of February 1961 and on receipt by the author from January through February 1961.

[b] On opening carton containing closed-cell "neoprene" rubber closures an extremely unpleasant odor came from the closure strips. According to the manufacturer, this odor was due to the residues of the chemical blowing agent, after decomposition. It should also be borne in mind that most blowing agents are highly flammable and sometimes toxic. This might be found objectionable in certain installations.

PLATE II

Comparison of Length of Closure Strips After Weathering Test[a]

PLATE I



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[a] Actual, unretouched photograph of weathered closure strips laid on a grid for measurement. Cf. Weathering Test, p. 11.

TABLE 2

LINEAL SHRINKAGE OF CLOSURE STRIPS AS RESULT OF WEATHERING TEST

Closure Strip Material	Original Length	Weathered Length	Lineal Shrinkage as Percentage of Original Length
Rubber–Solid	28″	28″	0%
Rubber–Open-Cell	28″	24¾″	–12%
Rubber–Closed-Cell	28″	25½″	– 9%
Polyethylene Foam	32″	30½″	– 5%
Polyurethane Foam	32″	30″	– 6%
Vinyl Foam	37¾″	34″	–10%

once a week the strips were separated and placed again in the position they would ordinarily weather in a building installation.

The box was constructed and mounted so that sun, rain, and dirt would easily run off. No attempt was made to remove snow or ice, however.

The strips, then, had full weather exposure to the latter part of the winter of 1961, the full summer and fall of 1961, a particularly severe winter of 1961-62, and the spring of 1962—a total of fifteen months of exposure.

Results of the Weathering Test

Length of the Strips.—Plate II is a photograph of the test closure strips mounted after the weathering test exposure—to show their weathered length. It can be seen that all sponge (cellular)—both rubber and plastic—closure strips shrank in length during the fifteen-month test. Table 2 shows the extent of the shrinkage of the sponge (cellular) closure strips contrasted with the solid or dense rubber closures on test.

Such shrinkage experienced in the relative short fifteen months test would only mean that the sponge (cellular) closure strips would lose its gasketing properties rather quickly after installation.

Thickness of Weathered Strips.— Table 3 gives the change in thickness of the test closure strips before and after weathering. Several measurements were taken to verify the thickness after weathering to avoid parts of the strips which might have become slightly compressed during the testing period.

The shrinkage in thickness of all sponge (cellular) closure strips plus their poor compression set [22] would seem to make the cellular material entirely unfit for this application.

Plate III illustrates the poor sealing found in many field installations visited, using closed-cell

TABLE 3

CHANGE IN THICKNESS OF CLOSURE STRIPS AS RESULT OF WEATHERING TEST

Closure Strip Material	Unweathered Thickness	Weathered Thickness	Net Change
Rubber–Solid	1 1/16″	1 1/16″	0%
Rubber–Open-Cell	1 1/8 ″	31/32″	–14%
Rubber–Closed-Cell	1 1/16″	1″	– 6%
Polyethylene Foam	1 1/4 ″	1 1/8 ″	–10%
Polyurethane Foam	1 5/16″	1 1/4 ″	– 4%
Vinyl Foam	1 5/16″	1 3/16″	– 9%

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[22] Cf. p. 23.

PLATE III

Sealing Performance of Closed-Cell Rubber Closure Strips after Five Years' Installation.

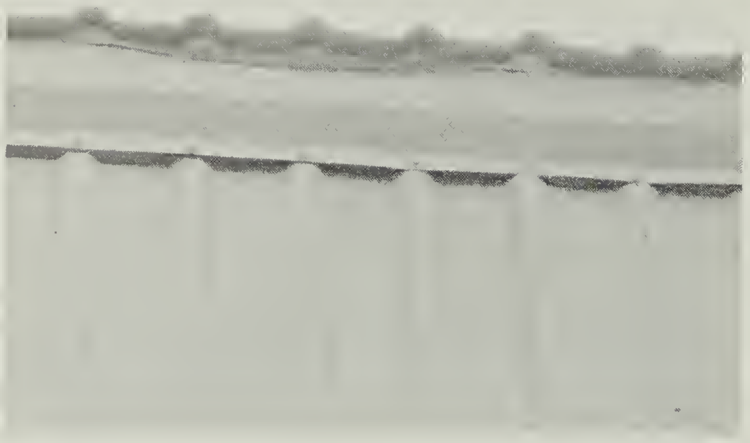

Fig. a

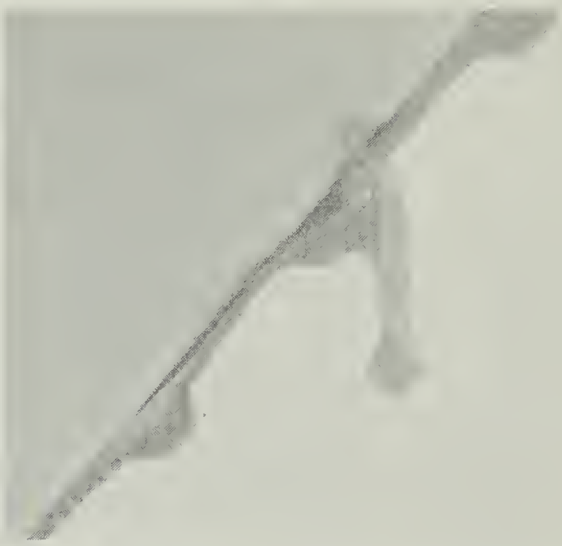

Fig. d

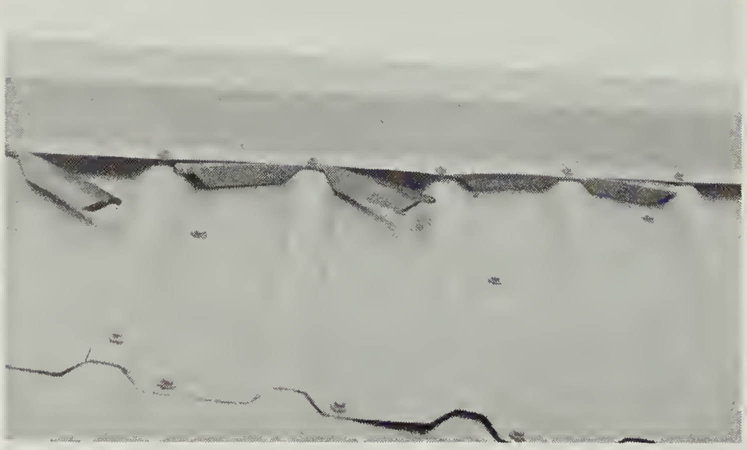

Fig. b

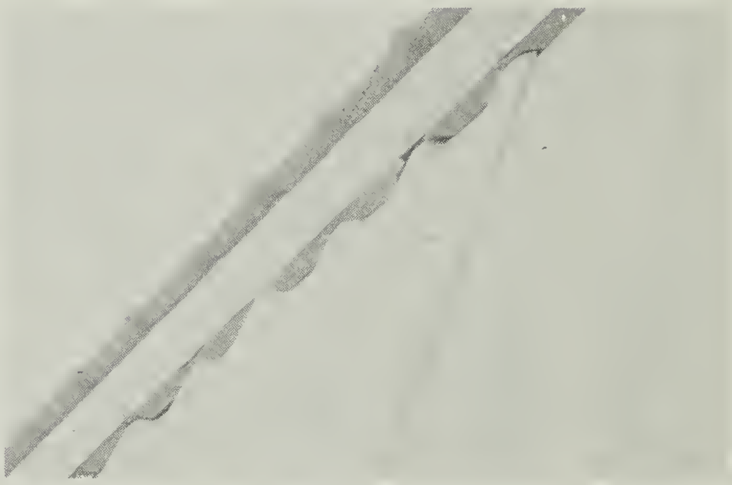

Fig. e

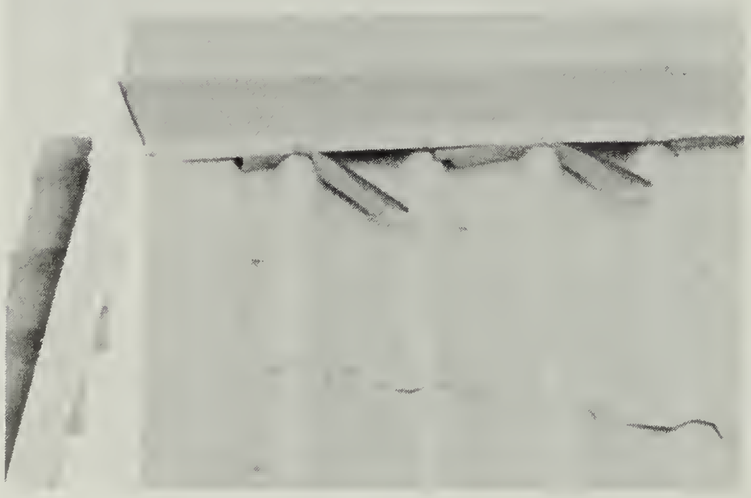

Fig. c

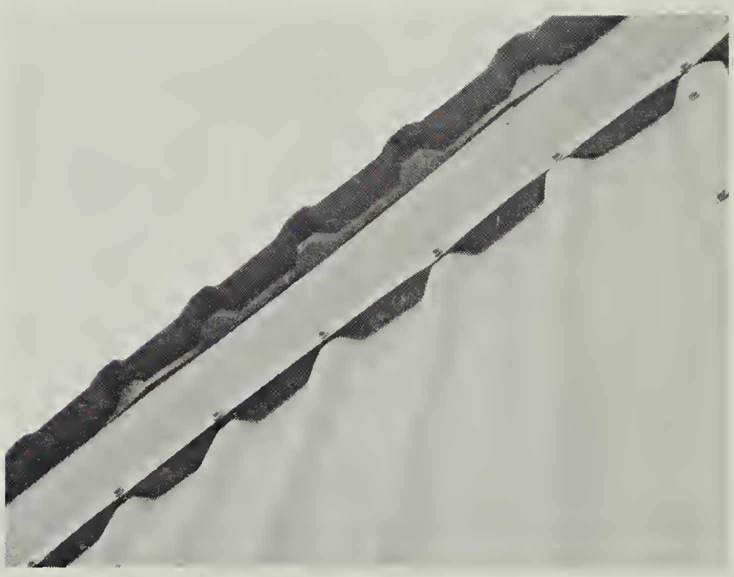

Fig. f

Figures (a) through (f) are actual, unretouched photographs showing the closed-cell rubber closure falling out and broken at eaves, at gable ends, and door heads of a pre-fabricated steel hangar building located at the Municipal Airport, Fort Madison, Iowa.

TABLE 4

WEIGHT LOSS AND CONDITION
OF WEATHERED CLOSURE STRIPS

Closure Strip Material	Weight as Received	Weight after Weathering	Condition after Weathering
Rubber—Solid	7 oz.	7 oz.	Slight yellowing at edges No visible cracks
Rubber—Open-Cell	4.5 oz.	3.1 oz.	Pronounced brown color, surface hard, severe checking, break in hand
Rubber—Closed-Cell	5 oz.	4 oz.	Surface hard, yellowing, dried out
Polyethylene Foam	2.9 oz.	1.5 oz.	Gray-brown, ends shriveled, severe cracking lengthwise
Polyurethane Foam	1.3 oz.	1 oz.	Surface hardness increase, surface powdery
Vinyl Foam	1.9 oz.	1.7 oz.	Very brittle, broken in thin sections

rubber or plastic closures. The closures, on weathering, had shrunk, become brittle, and broken off. Over twenty per cent of the sealing was gone due to the dimensional shrinkage—both in length and thickness—of the sponge (cellular) closure strip.

Weight Loss of Weathered Strips.—As the closure strips were taken off the test rack, a noticeable increase in hardness of the sponge (cellular) strips was noted.[23]

It was known that relatively large quantities of oils and plasticizers are commonly used in chemically blown sponge compounds. Furthermore, with more of the surface of the cellular closure exposed to the weather than the solid closure, a much faster rate of weathering could be expected. The result of faster weathering, accompanied by loss of plasticizers, would result in increased hardness of the closure.

The tendency of a cellular product to lose weight upon aging, through evaporation of the plasticizers or softeners is normally measured by weight-loss. Table 4 details the weight loss and condition of the cellular types of closure after weathering with its solid rubber counterpart. Up to 48% loss in weight of the cellular-type closure was evidenced in this weathering test. On top of this, the cellular product had not only lost its elastic, sponge properties, but was, in some cases, too brittle to be of use as a closure.[24]

Results of Other Environmental Exposure Tests

Weathering

None of the cellular closure materials examined—open-cell rubber, closed-cell rubber, polyethylene foam, polyurethane foam, or (PVC) vinyl foam—passed the freezing-thawing cycle test. Water entering their cellular or sponge construction upon freezing, expanded and burst the thin-wall cells. The evidence of this breakage varied according to the water absorption characteristics of the material. The vinyl foam strip broke up completely. The solid rubber strip, on the other hand, had no visible evidence of breakdown.

Heat

As the above tests graphically illustrated, cellular products, because of their structure, exposed a large surface area of thin-walled material to destructive conditions. Thus, a cellular product—either plastic or rubber—was found more susceptible to deteriorating influences than the solid rubber closure. This was again reconfirmed in heat-aging tests.

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[23] Cf. p. 22.

[24] Great care should be exercised in using any cellular product with a thermoplastic plastic sheet—such as corrugated rigid polyvinyl sheets. While unusually resistant to acids, alkalis, and hydrocarbon oils, the chlorinated softeners and monomeric plasticizers used to make the flexible cellular products can cause a migration so great as to cause softening, tack development, and even surface cracking to the unplasticized corrugated rigid vinyl panel. Cf. W. S. Penn, *PVC Technology* (London: McLaren & Sons, Ltd., 1962), p. 119.

It was extremely difficult to compare cellular strips with the solid rubber strip. For, while the basic test data was based upon ASTM D-573, tests of cellular products were not concerned with a resultant change in tensile strength, elongation, etc. due to aging, but to a change in compression-deflection ratio as a result of aging.[25] Further complicating the comparison was the fact that some cellular plastics could not stand heat-aging and test data have been omitted from published literature.

The solid rubber strip tested extremely well in heat aging losing only 3% of its tensile, and approximately 10% elongation.[26] The sponge rubber (open-cell) strip, by contrast, became considerably harder, increasing its original load-deflection by 180%. Closed-cell (expanded) rubber strips also hardened, increasing the load-deflection approximately 105%.[27] Both open and closed cell rubbers shrank appreciably after the oven-aging test; the open-cell sponge to approximately 20% of its length, the closed-cell approximately 10% of its length.[28]

In the examination of the cellular plastics materials, it was found that polyethylene foam[29] distorted and seemed to melt around the edges, and lost about 5% of its volume.[30] Polyvinyl chloride (vinyl) foam and polyethylene cellular plastics were both thermoplastic.[31] These foams also had some tendency to stiffen at moderately low temperatures and soften at not-too-high temperatures.[32] Manufacturers recommended that polyethylene and polyvinyl chloride (vinyl) foam closures not be used in hot areas as both closures would deform at relatively low temperatures. Of the plastic foams examined, polyurethane appeared less affected by heat,[33] although at elevated temperature it has poor tear resistance.

In conclusion, it appears that at normal atmospheric temperatures most cellular products would be passable as closures but at the elevated temperatures, often encountered in roofing installations, their shrinkage and physical change under continuous service would not recommend them. Solid rubber closure materials appeared more qualified.

Cold

It would seem natural for an elastic gasket to become stiff at low temperatures. It was found that some materials would fail in service by shattering under impact when their brittleness temperature was reached. In nailing or fastening, others became too stiff to function as an "elastic" gasket. And, still others, because of moisture absorption, froze and broke before installation or gradually broke down during the freezing-thawing cycle typical of northern climates. This examination of the serviceability of a closure in low temperatures was confined to the "brittleness" temperature.

Most of the closures examined performed reasonably well in brittleness tests, either because of their heavy load of plasticizers or the nature of the elastomer or plastic itself. All cellular materials, however, tended to stiffen at slightly higher temperatures than solid or dense closures.[34] This was undoubtedly due to their thin-wall structure. Poorest performing were cellular rubbers and vinyl foam. Their brittleness point was reached between 0° to —20°F.[35]

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[25] Compression-deflection is defined as the unit load required, expressed in pounds per square inch to compress a given cellular thickness 25% of its own original thickness. (ASTM D-1056, Section 20-23)

[26] A synthetic and natural rubber strip (ASTM D-573 at 212°F for 70 hours).

[27] Manufacturer's specifications for this material was an increase or decrease of 20%.

[28] Manufacturer stated, "Maximum linear shrinkage after accelerated aging by oven test, seven days at 158°F should not be more than 3%." Note: Manufacturer's names have been purposely omitted since manufacturers differed in their "technical data" and advertising literature, from authorities in the field, and from this test series, conducted by an independent laboratory.

[29] Made of equal volumes of polyethylene and gas.

[30] Manufacturer's bulletin said: "Volume change on heat aging 140°F—dry heat for seven days—less than 1% volume." Also, ". . . exposed to Arizona sunlight,—some degradation after three months." Chemical literature, reviewed, simply stated: "Not recommended near heat. Extremely thermoplastic."

[31] "Thermoplastic, adj.—capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature." Randolph, *op. cit.* p.li.

[32] Manufacturer's instruction stated variously: "Poor heat resistance. . . . There is some shrinkage of closed-cell PVC foam. . . . A prolonged sunlight exposure could affect the plasticizer, resulting in a stiffening and eventual brittleness of the product." One manufacturer stated in a letter: "I could guess this product could be used in the temperature range common to other vinyl products, that is between -50°F and +150°F." But, Randolph, *op. cit.*, p. 51 stated: "Vinyls tend to be decomposed chemically by prolonged exposure at high temperature." Finally, maximum recommended continuous service temperature is below 110°F. Cf. *Technical Data on Plastics* (New York: Manufacturing Chemists Association, Inc., 1957), p. 194.

[33] One manufacturer's brochure, however, stated simply: "Poor heat resistance."

[34] Cf. ASTM D-797 and D-1053 were used to measure stiffness, by measuring increased modulus in flexure or torsion. Differences of between 7° to 16° were recorded.

Flammability

The table below gives the flame-spread rating of the closure materials available. The burning rate ran from very rapid to slow. Solid rubber was hardest to start burning; the PVC (vinyl) foam, like other cellular products, was quickly ignited, but, in contrast, was extremely slow burning. Open-cell rubber burned very rapidly. Special compounding of both solid rubber[36] and polyethylene foam[37] were reported to give compounds with flame speed rating of "slow".

TABLE 5

FLAME-SPREAD RATING OF CLOSURES[a]

Closure Strip Material	Rating (inches/min.)
Rubber—Solid	1.75[b]
Rubber—Open-Cell	4.90
Rubber—Closed-Cell	3.00
Polyethylene foam	8.30
Polyurethane foam	3.80
Vinyl foam	.50

[a] Plastics tested by ASTM—D-635; rubbers by MIL-STD-417 (ORD), Suffix M.

[b] Slow-burning or self-extinguishing grade available.

The important point would seem to be, as far as the flammability of the closure is concerned, is that when one encases a low burning material with relatively fire-proof materials—there isn't much of a fire hazard left. In addition, even if it were not connected to fireproof materials, the contribution made to a fire by so few pounds of material would be inconsequential. However, it would appear that open-cell rubber, polyethylene and polyurethane foam closures could not be recommended because of high flammability.

Ozone

No attempt was made to measure the closures examined by accelerated ozone cracking tests. From literature and engineering data, all were thought to possess fair to good ozone resistance.

Thermal Insulation

TABLE 6

THERMAL CONDUCTIVITY OF CLOSURE MATERIALS[a]

Closure Material	"K" Value
Rubber—Solid	.95
Rubber—Open-cell	.60
Rubber—Closed-cell	.75
Polyethylene foam	.85
Polyurethane foam	.25
Vinyl foam	.31

[a] Source: ASTM-C-177

Table 6, above, gives the coefficient of heat conductivity of the various closure materials. Interpreted with other materials of construction (Table 7 below), the vinyl foam closure would be rated as excellent, the solid rubber closure good.

Soft solid rubber may vary in "K" Value from .90—1.1. The corrugated sheets, with which the closures are used, have coefficients much larger; asbestos-cement sheets—5.2; glass—6.0; steel—

TABLE 7

THERMAL CONDUCTIVITY OF HEAT INSULATING MATERIALS USED IN CONSTRUCTION[a]

Material	"K" Value
Asbestos	.516-1.62
Concrete	2.2
Glass wool	.88
Leather	1.10
Paper	.90
Plaster	1.7-4.4
Wood	1.2

[a] Norbert A. Lange, *Lange's Handbook of Chemistry* (Sandusky, Ohio, Handbook Publishers, Inc., 1956) p. 876.

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[35] PVC (vinyl) foam manufacturer's literature claimed: "suitable for use at continuous temperatures between -30°F and +150°F without substantial loss of performance characteristics." Engineering handbooks gave: "—low temperature failure of polyvinyl chloride foam between -10° and -15°C (+*14*°F and +5°F)."

[36] Pure gum rubber has a high calorific value—a measure of contribution which a burning article can give to total heat of conflagration. Many assume this applies to all "rubber," forgetting that up to 80% of a rubber product may consist of incombustible materials. It all depends on rubber "compounding." One can get an essentially self-extinguishing material.

[37] Far from being the material that "looks, smells, and burns like a candle," it is understood that, specially compounded, its flame resistance can be lowered appreciably.

Figure 4—Results of Installation of Cellular (Foam) Closures in Gutter of Prefabricated Steel Building[a]

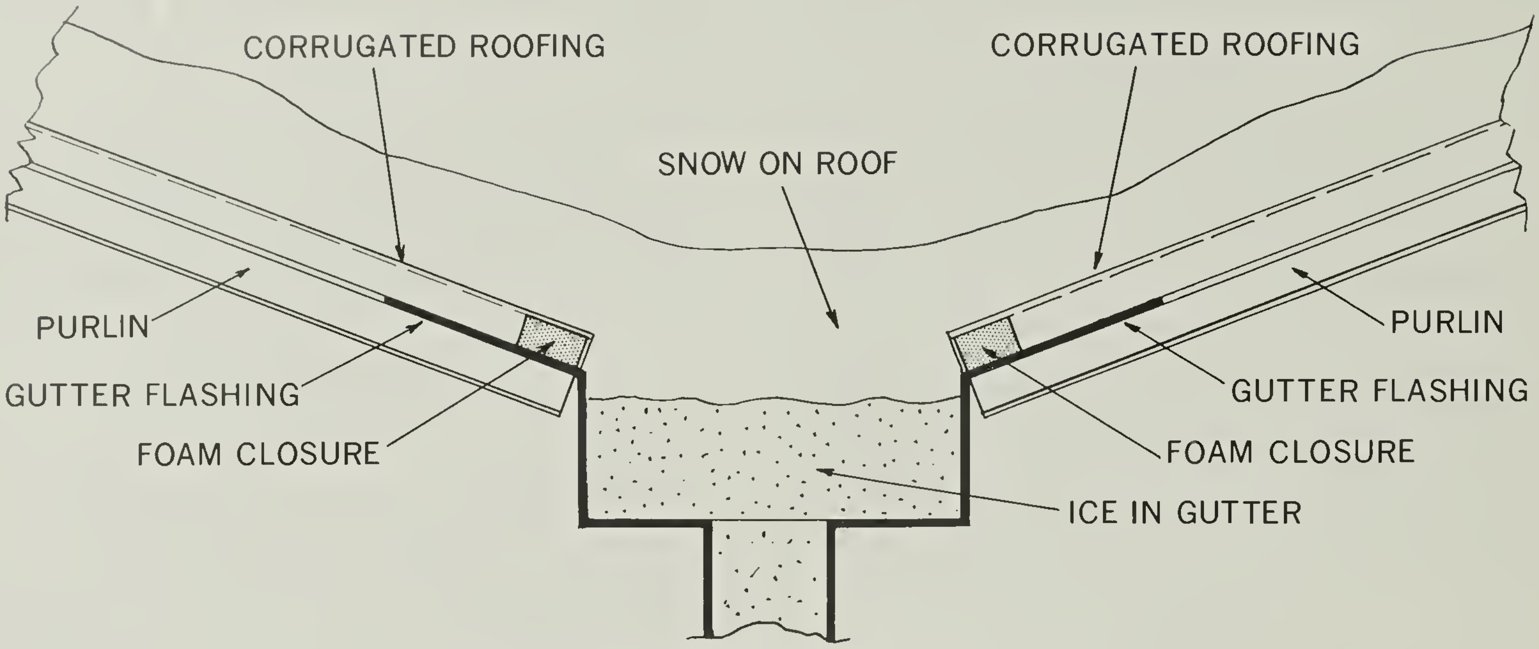

Fig. a - Following snow and freeze

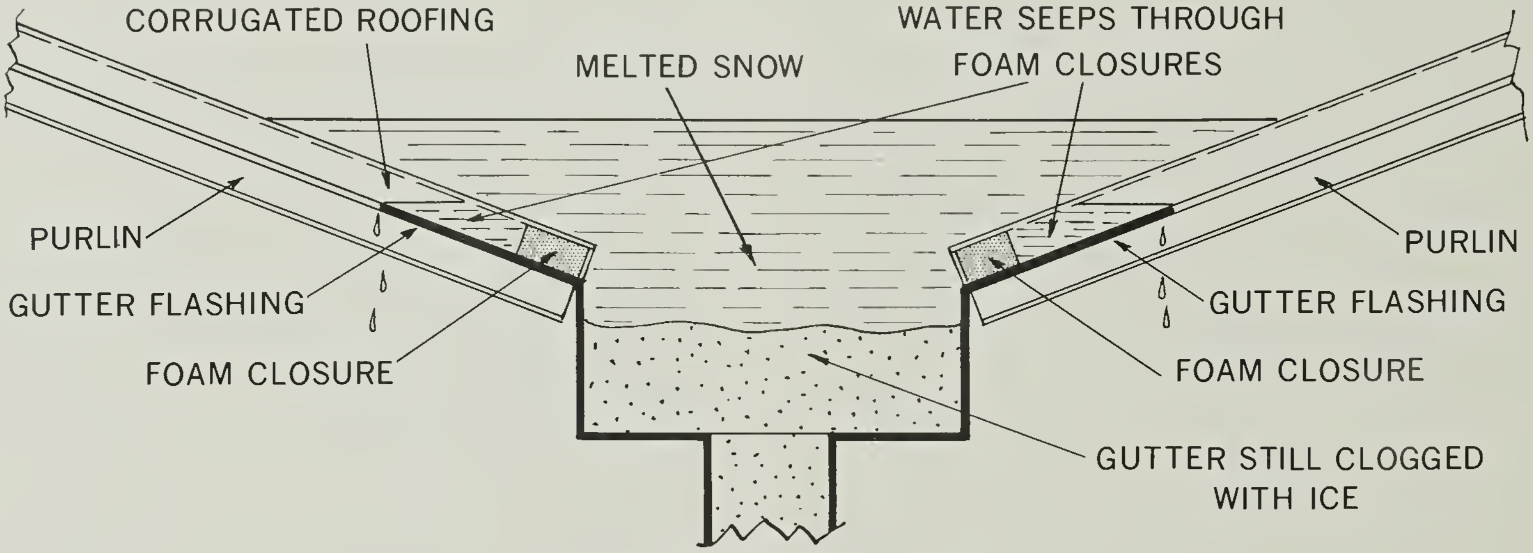

Fig. b - 14 days later

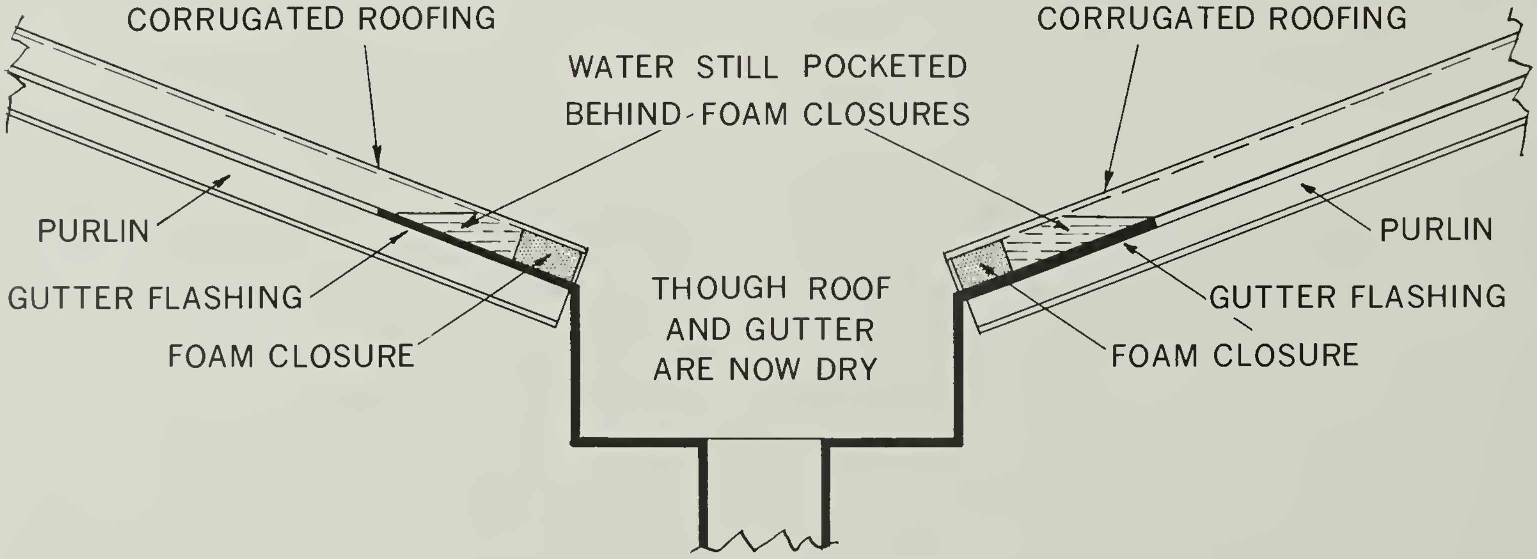

Fig. c - 21 days later

[a] Source: Experience encountered in manufacturing facility, Winnebago County, Wisconsin.

312; aluminum 1,416. Thus, all of the closures examined might be rated good to excellent in insulation value.

Water

The water "resistance" of closures differed depending on whether the closure was cellular or solid. Solid rubber did not absorb water. Cellular rubbers did in varying degree.[38] The water absorptive nature of the cellular closure would seriously affect its performance as an all-weather gasket. Water absorption varied,[39] but all cellular closures absorbed water,[40] and had lower physical properties because of the absorption.[41]

Figure 4 shows the step by step results of a gutter installation of cellular closure strips "mistakenly" installed in a large factory building in Winnebago County, Wisconsin. The contractor and the plant manager described it to the author as follows:

> "Heavy snows and frozen downspouts made the gutters overflow the corrugated roofing. Water poured through those d--- sponge strips on our expensive machinery below."

As the men walked down the now dry gutter, stepping occasionally on the edge of the roof, water squirted out of the sponge closures. The plant manager said:

> "But, the worst of it is that these strips are still wicking water into our building."

Whether cellular closure strips with relatively high water absorption characteristics would "wick" water into otherwise tight structures or not, the cellular closure would fail in freezing-thawing cycle performance.

Measurement of Dynamic Requirements

Comparison—Deflection Values

Figure 5 illustrates the relative load-carrying ability of the closure in its various commercial materials. Of these, only the soft solid rubber closure had anything approaching the load requirements of the corrugated materials with which the closure is used.[42] In addition, the sponge and foam closures examined exhibited a plateau effect in their respective compression-deflection curves— the percentage of compression increasing rapidly under a steady load. Finally, as was later discovered, all sponge and foam closures took a permanent compression set, once distorted by a load.

Tensile Strengths

The tensile strength[43] of the solid soft rubber closure, a low value in comparison with conventional rubber stocks,[44] has five to ten times the level of value of sponge or foamed materials as illustrated in Figure 6. In a general way, the elastomer and plastic fields have agreed that ultimate tensile strength is a rough indication of quality. And, while the failure of this product

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[35] Some closed-cell products have been used as water floatation gear, life saving belts, and outer apparel for scuba divers. Thus, the water-absorption data gathered here might seem inconsistent. Explanation for the apparent inconsistency was that the water-used product was in some instances a different composition of the cellular product, possessed skins or covering not appearing in the closure strip, and was of different density. In addition, many cellular products, adapted to water-use, were up to thirty times lighter than water.

[39] One manufacturer's bulletin reported: "water vapor transmission rate four-tenths of a gram per hour, through one square foot, one inch thick."

[40] Sponge (open-cell) rubber absorbed up to 20% by weight. Closed-cell rubber—although specified as "water absorption by volume shall not exceed 2½%—absorbed between 5 and 10% by weight. Polyethylene absorbed 4% by volume. (An engineering bulletin on this material was extremely contradictory: "Permeability to moisture is high.—It is water-resistant.—will absorb moisture after immersion in increasing quantity depending on days immersed.—no moisture or dust can penetrate.") On polyvinyl chloride foams, from literature: "Water absorption .40%; Alan F. Randolph, *op. cit*, p. 193: "water-absorption, lbs./ft. of cut surface 0.1"; manufacturer wrote: "On—experience would indicate that this product would absorb no water after 24 hours exposure." Urethane foams had the highest water absorption, up to 30%.

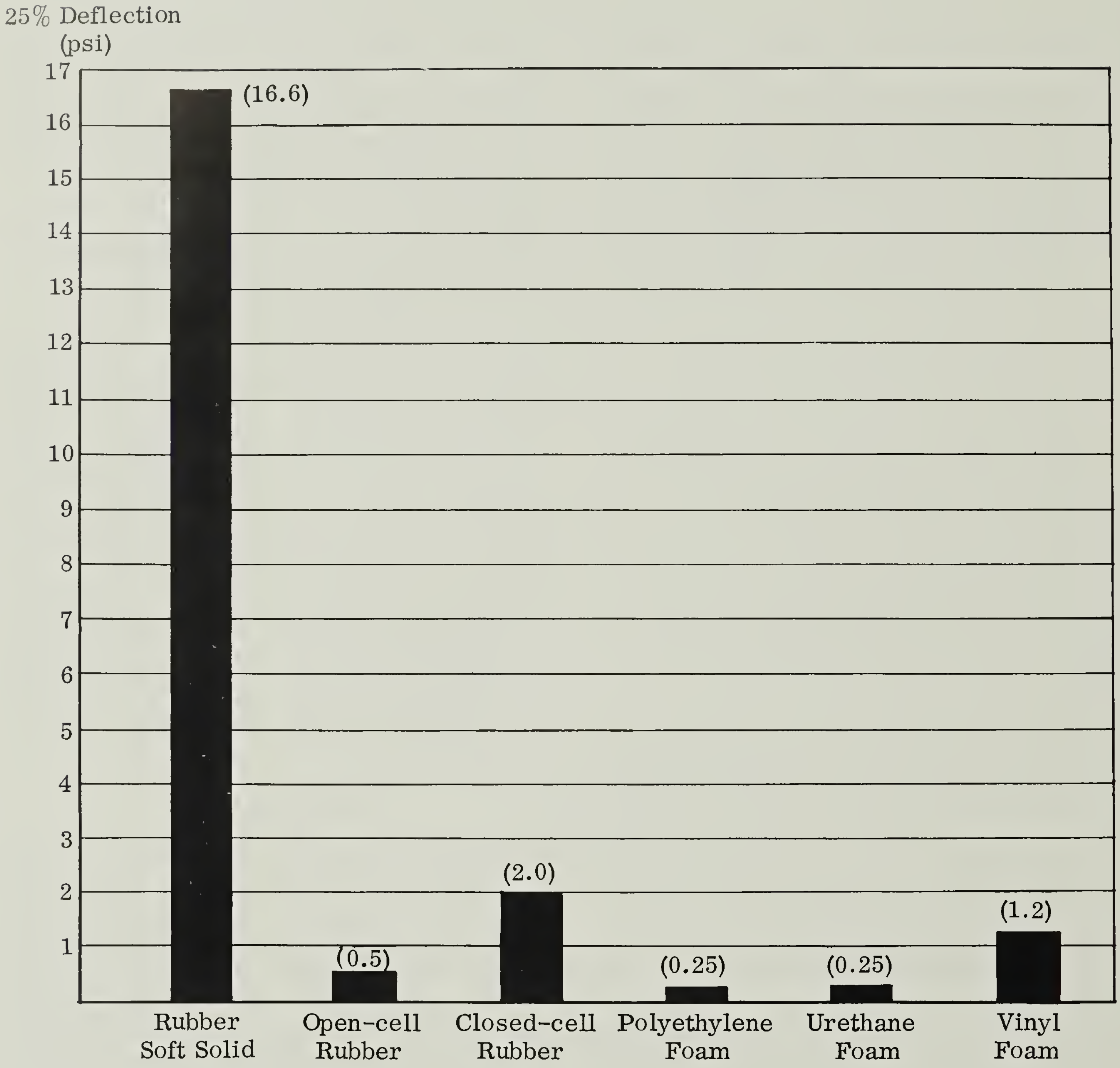
[41] Polyurethane foam was clearly most affected by water immersion. Manufacturer's brochures detailed: "Subject to some degree of hydrolytic degradation (a chemical process of decomposition involving addition of the elements of water). "Change in tensile strength (7%) in water immersion: -47% (wet) -8% (dry)."

[42] It should be noted that the pounds per square inch must be converted to pounds per square foot for a comparison to be made. Cf. p. 7.

[43] "This is defined as the force per unit of the original cross sectional area which is applied at the time of rupture of the Dumbell test specimen." Cf. George G. Winspear, ed., *The Vanderbilt Rubber Handbook*, (New York, R. T. Vanderbilt Co., Inc., 1958), p. 211.

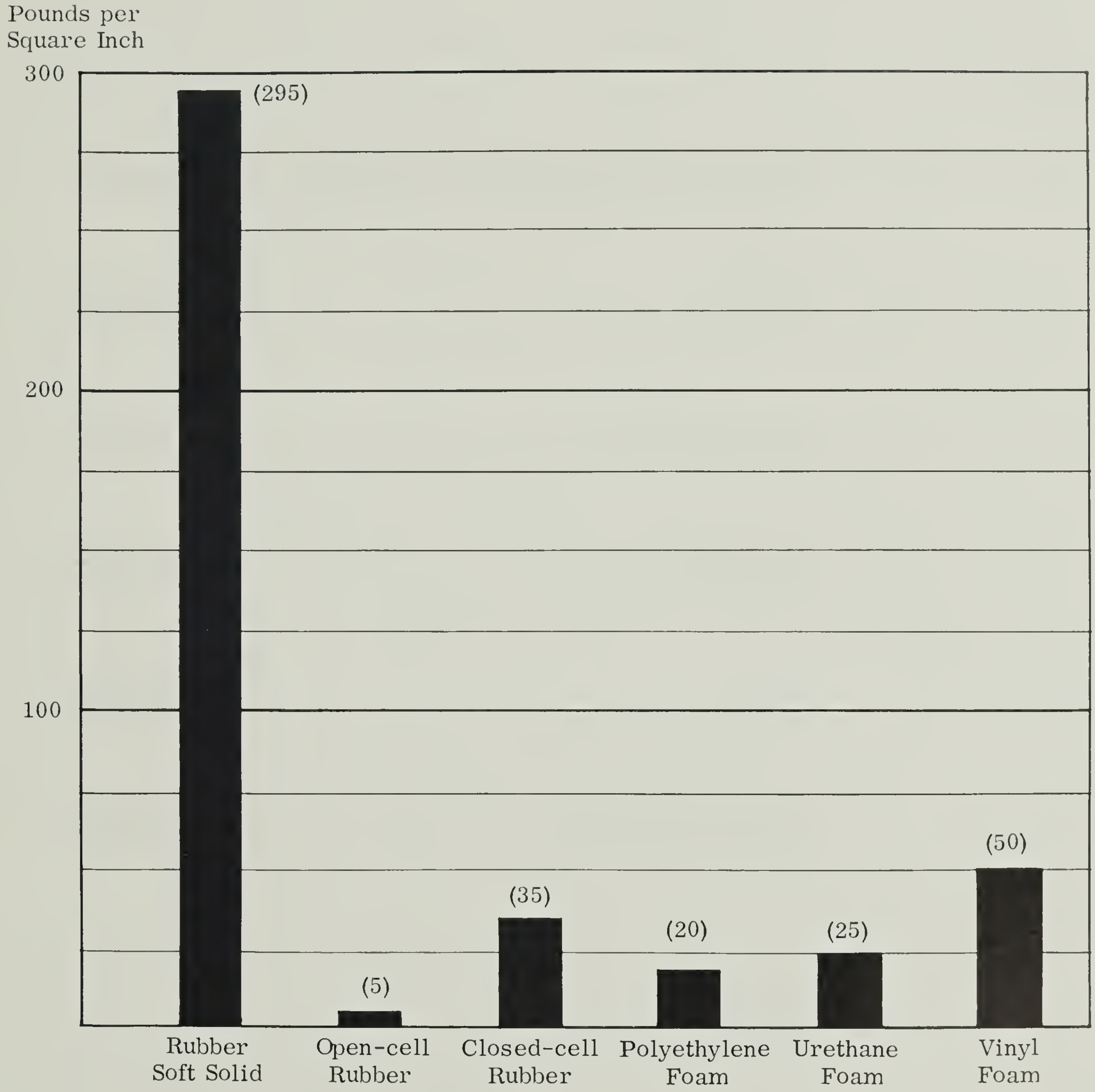
[44] SAE-ASTM Technical Committee on Automotive Rubber does not classify elastomer compounds below five hundred pounds per square inch. However, materials of low tensile may give good performance in certain products as does much higher quality material. Cf. *1961 ASTM Book of Standards*, op. cit., p. 299ff.

Figure 5—Compression-Deflection Values of Materials Used for Closure Strips[a]



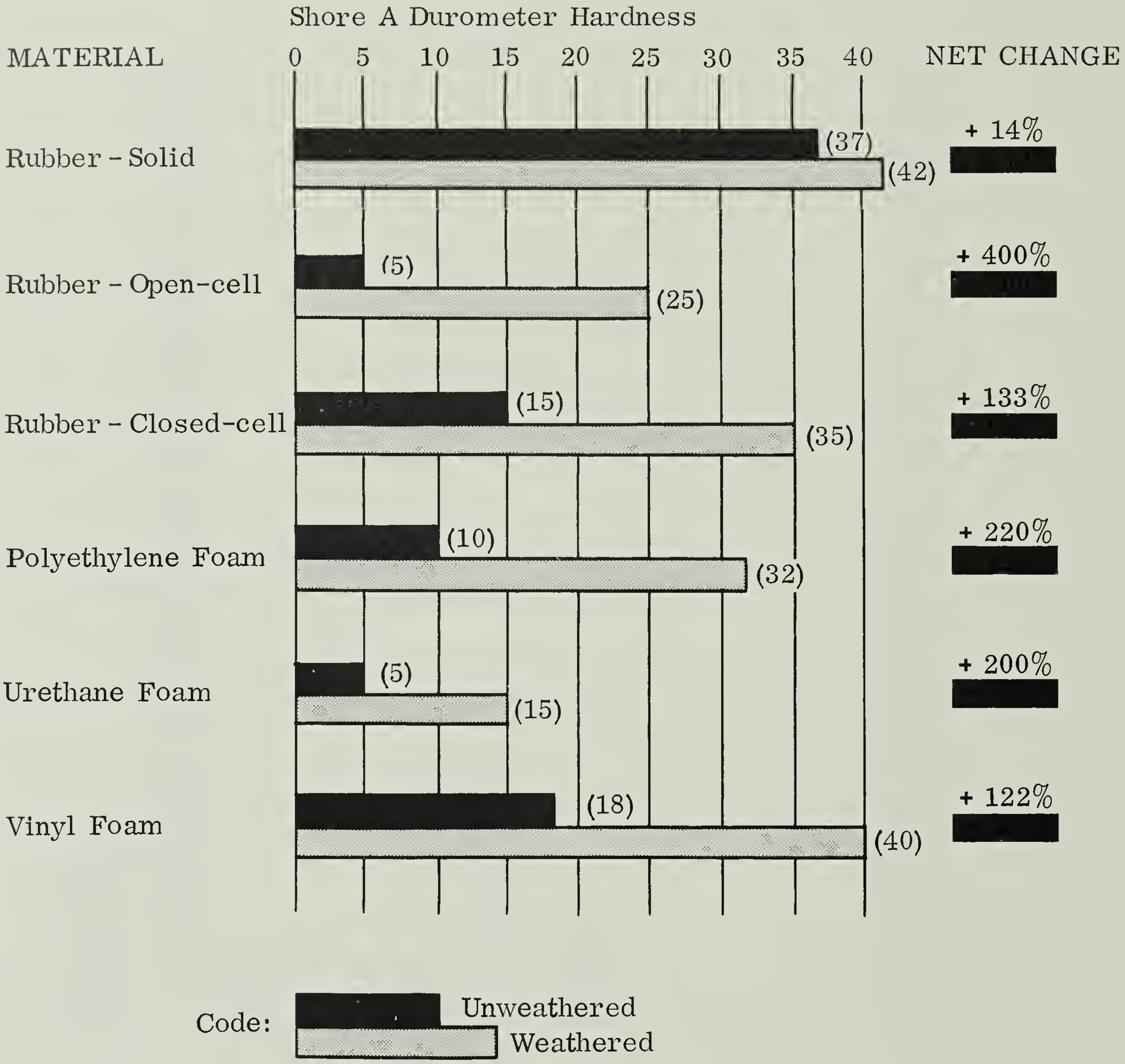
[a] Source: Manufacturers' literature and independent laboratory tests, December 1962. This unit-load requirement was omitted from much of the published data of fabricators of sponge or foam closures. Where lacking, data was ascertained from manufacturers of the sponge or foam material itself. Even these producers gave what might be considered rather ambiguous statistics to a standard specification in the cellular field. Cellular polyethylene manufacturers, for example, stated: "Deflections of 25% gives a work energy loss of 56%." And, again, a urethane foam producer published: "15% deflection 0.20 psi; 30% deflection 0.29 psi."

Figure 6—Comparison of Tensile Strengths of Closure Materials[a]



[a] Sources: Independent laboratory tests, manufacturers' literature; "Technical Data on Plastics," op. cit., p. 194-195; and Alan F. Randolph, ed., op. cit., p. 136 ff.

Figure 7—Comparison of Weathered and Unweathered Closure Strip Hardness.[a]



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[a] Cf. Weathering Test, p. 11.

in service may be less influenced by the stress-strain property failure, a minimum tensile value would seem to indicate a tendency towards failure of the product under its normal physical and dynamic requirements.

Since "elongation" is but another phase of the standard tensile or stress-strain measurement, the values were omitted from this study. Most applicators in the field, however, felt that a closure needed to stretch at least once again its own length.

Hardness

One of the prime advantages of the cellular type closure should be its ability to conform to the irregularities of corrugated sheeting. And, measuring the original unweathered hardness of the closures examined, their "softness" was outstanding.[46]

However, the weathered hardness of all but one of the closure materials examined varied but a few durometer points (Figure 7). In their function as closures, though, the cellular closure strips at the (weathered) higher durometer, were brittle, powdery, and, in some instances, broken in the thinner sections.

In practice, it was found desirable that a maximum of 40 Shore A durometer (medium soft-ASTM D-676) not be exceeded. Specially designed solid closure strips of this durometer or higher, however, were reported most satisfactory in conforming to irregularities.[47]

Compression Set

The resistance of the solid rubber closure to permanent deformation, when subjected to compression, stress, was clearly superior when compared with its cellular substitutes—Figure 8. The extent to which distortion, expressed as a percentage of the original thickness, had become permanent is here expressed by a "compression set" value.

For example, the PVC (polyvinyl chloride) or vinyl foam strip, even when tested at room temperature, only recovered 15% of its original height—after a 24 hour recovery. Urethane foam closures had the poorest compression set recovering only 2% of their original thickness.

As explained earlier in the study,[48] compression set, being the property which prevents the closure material from recovering its original thickness or height (after it has been under compression for a period of time and released from the compressing force) is an extremely important criteria in choosing a material for the closure strip.

The more nearly the closure material returns to its original height, the lower the compression set. In the tests given here, rubber returned within 81% of its original height, urethane returned to only 2% of its original height. Or, expressed another way, when a 1 inch thick portion of the urethane closure strip was compressed to .50 inch, and the load removed, it would return to only .51 inch. The solid rubber strip, under the same circumstances, would return to .905 inch.

The examples sighted just above, however, are not quite comparable since the solid rubber strip had to be subjected to 22 hours at 158°F to even distort this much, while the urethane strip would permanently distort at just room temperatures. And, in addition, it was discovered that if the load was not taken off, all cellular closures would eventually collapse completely.

Given the expansion and contraction of the materials of corrugated construction, and ordinary building movement, very low compression set is desirable in closure stripping, when the closure gasket is compressed for various periods of time, and then must spring back to near its original shape in order to seal the opening when pressure is reapplied.

Plate IV compares the compression recovery of the solid rubber closure and the polyethylene foam strip. The insert photograph shows short lengths of the solid rubber closure and foam polyethylene strip compressed 50% in a clamp, where the solid rubber was held 22 hours at 158°F (warming accelerates the effect of time) and the polyethylene foam held the same length of time at room temperature (polyethylene foam

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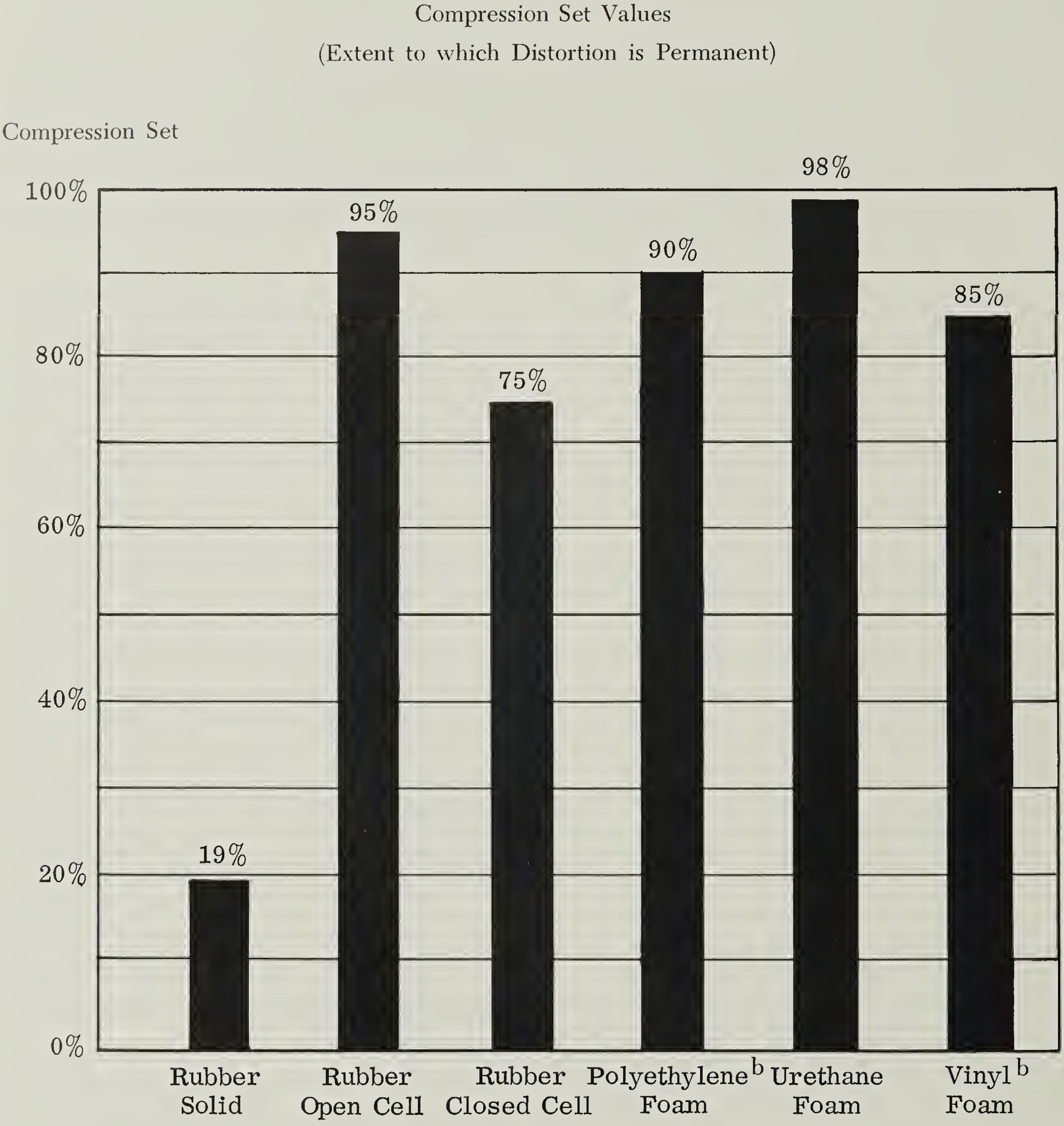
[46] Cellular materials customarily measure their "softness" by "density" (weight per cubic foot) and, where possible, by indentation load deflection. Solid elastomers, on the other hand, commonly measure this value by indentation of a durometer—Shore A being typical. At readings below 20 (on a scale from 0—100, soft to hard respectively) the durometer is admittedly inaccurate.

[47] Closures with flexible flanges, special soft ribs or flaps, were claimed to provide excellent sealing.

[48] Cf. p. 9.

Figure 8—Compression Set Values for Test Closure Strips Measured According to ASTM-D 395, Method B[a]



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[a] Sources: Manufacturers' literature and laboratory tests. Percentage of compression employed: 50%.

[b] Since closure material melts at test temperature (158°F), tests are made at room temperature with a 24 hour recovery period.

PLATE IV

A Comparison of Compression Recovery
of Solid Rubber Closure and Cellular Closure[a]

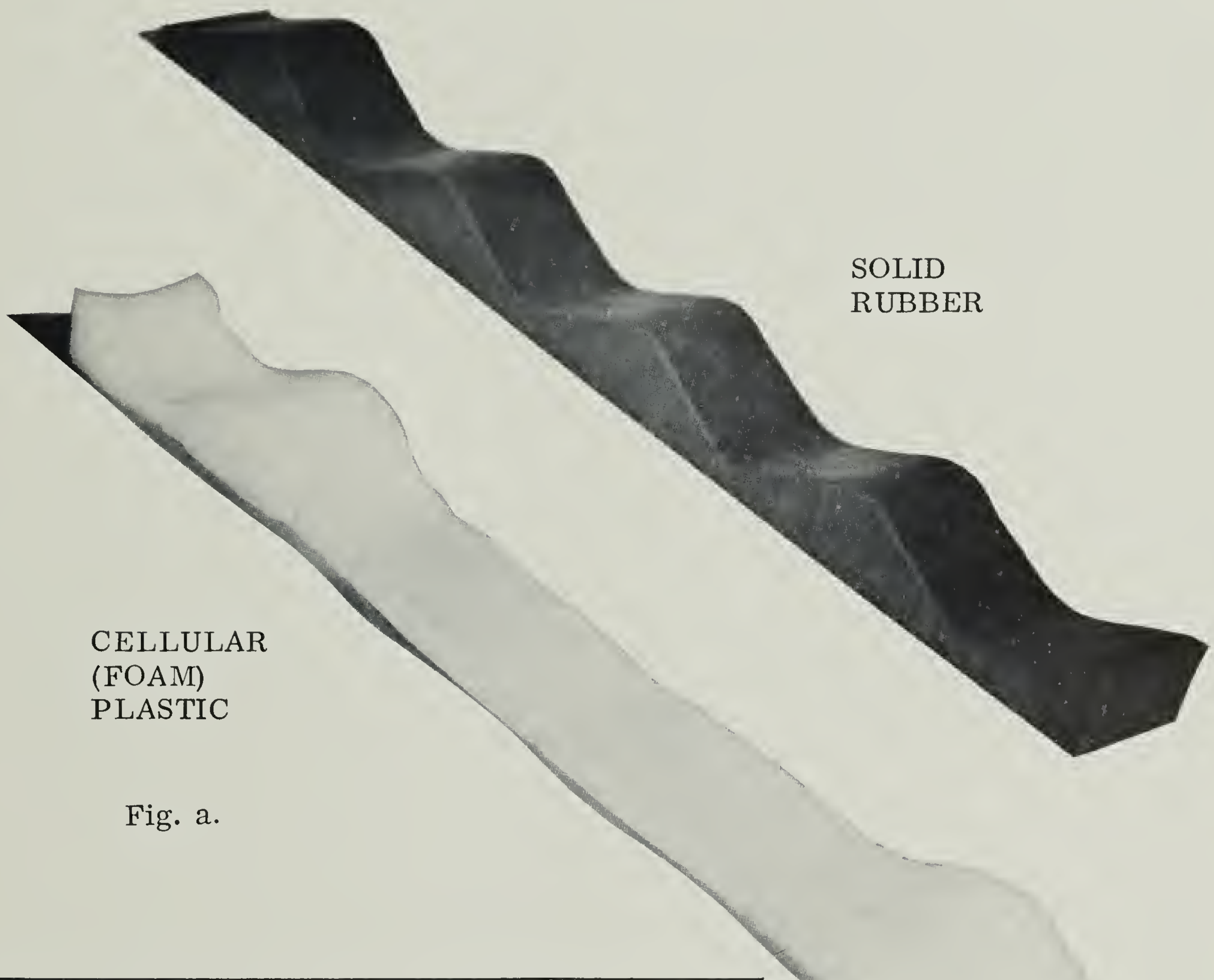

Fig. a.

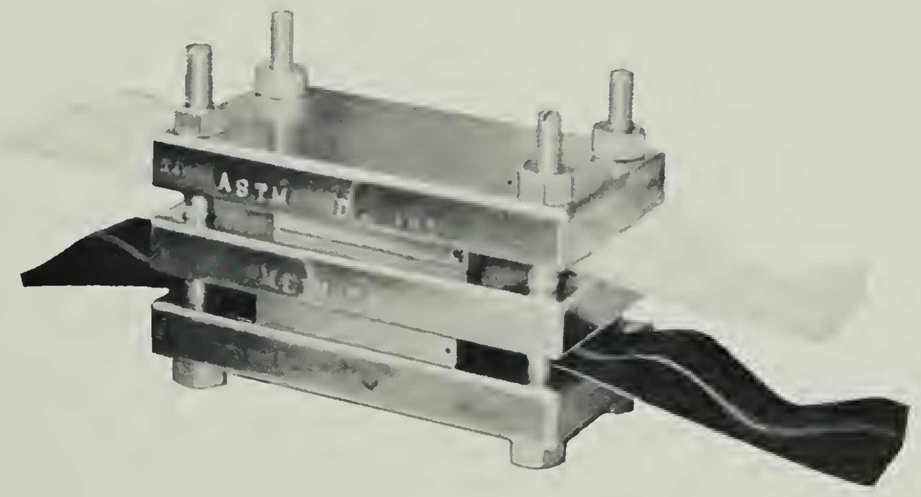

Fig. b.

[a] Unretouched photographs of actual laboratory test and results as described on p. 23

can't stand high temperatures). The large photograph shows the specimens after removal from the clamp. The solid rubber closure recovered its original shape immediately.[49]

Summary

As in the comparison of compression sets of closure materials just illustrated, differences and similarities in closures were all examined to the requirement standards previously set up. Weathering tests found cellular strips shrinking dimensionally as high as 11% in length and 14% in thickness. On closer examination this was found to apparently be due to the cellular closure's ingredients and the thin-walled nature of the product.

Freezing-thawing cycle tests broke down all cellular closure strips; heat aging melted the thermoplastic plastic cellular strips and shrank cellular rubber products. All closures (except PVC vinyl foam) survived brittleness tests. Open-cell rubber, polyethylene and polyurethane materials were considered too flammable for closure applications. On the other hand, the thermal conductivity (insulation value) of most closure strips examined was rated uniformly "good" to "excellent". Again, however, environmental tests for water absorption proved all cellular closures unsatisfactory.

In another area of study, the dynamics required of the closure were met only by the solid, dense rubber material. Cellular closures initial 'softness" gave below-standard results in compression-deflection, tensile, and, most unfortunately, compression-set tests. And, the initial "softness" of the cellular materials hardened considerably after only fifteen months of weathering. Moreover, in the most important closure function—compression and recovery—cellular products failed completely. After once being compressed their gasketing effect was entirely gone.

The findings of this study—designed to discover what is required of the closure, what alternatives are offered, and how best to choose among these alternatives—are summarized by a chart of the technical data on these closure strips in the next section. It is hoped this chart will be of particular aid to architect and buyer, and that the sample specification appended will also be useful.

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[49] The result here could have been predicted from the very "definition of rubber" (ASTM D-1566) which reads, in part: "*Rubber* is a material which is capable of recovering from large deformations, quickly and forcibly . . ." Cf. "Technical Committee Notes" *Materials and Research Standards*, Vol. 2, No. 11 (November 1962), p. 939.

Figure 9—Technical Data on Closure Strips[a]

PROPERTY		ASTM TEST METHOD	RUBBER			POLYETHYLENE FOAM	POLYURETHANE FOAM	(PVC) VINYL FOAM
			SOLID	OPEN-CELL	CLOSED-CELL			
Tests for Dynamic Requirements	Tensile Strength psi	D-412	200-600	5-10	30-40	20-60	15-40	15-60
	Hardness Shore A	D-676	10-40	5	15	10	5	18
	Compression-Deflection 25% psi	D-575	16-35	0.5	2.0	0.25	0.25	1.5
	Compression Set After 22 Hrs. @ 158°F—50% *@ Room Temperature	D-395	20%	95%	75%	90%*	98%*	85%*
	Specific Gravity	D-792	0.97-1.25	0.55	0.70	0.4-0.5	.024-.063	.05-.18
Tests for Environmental Requirements	Migration-Stain	D-925	Negative	Some	Little	Some	Negative	Some
	Freezing-Thawing Test	—	Pass	Fail	Fail	Fail	Fail	Fail
	Heat Aging—70 Hrs (158°F)	D-573	Pass	Fail	Fail	Fail	Fail	Fail
	Brittleness—Cold (—40°F)	D-746	Pass	Fail	Fail	Pass	Pass	Fail
	Ozone Resistance	D-1171	Pass	Fail	Fail	Pass	Pass	Pass
	Water Absorption	—	Negative	Fail	Fail	Fail	Fail	Fail
	Heat Resistance (Max. Rec. Cont. Service Temp.) °F	—	190	120	120	110	150	115
	Thermal Conductivity BTU/Sq Ft/Hr/ °F/in.	C-177	0.95-1.10	.60	.75	0.65-0.85	0.2-0.25	.23-.31
	Flammability Over .050″ Thick In./Min.	D-635	.50-3.5	4.0-6.0	3.0-6.0	5.0-8.5	.50-3.0	.35-.70

[a] Source: Independent laboratory tests. The facts stated, and the recommendations and suggestions contained herein, are based on experiments and information believed to be reliable. Their accuracy is not guaranteed, however, and no warranty is made as to any use or application of any product.

IV. CONCLUSIONS

Summary of Findings

Corrugated construction appeals to architects and contractors because of its simplicity and economy. With all its advantages, however, this type of construction presents the problem of sealing the corrugated or ribbed panel to its structural framework and surrounding flat-surfaced materials.

With the growth of this type of construction since World War II, a number of flexible, elastic, rubber-like materials have been used to perform the sealing job—the function of the closure strip. This study has undertaken to find the closure material which best meets the requirements of an all-weather sealing gasket. It concluded that closure strips made of solid, soft rubber, presented the only solution to the problem.

Investigating the performance and qualities required of its closure, the study concluded that the physical specification for the closure strip must include the usual criteria of an elastomer: specific gravity range, hardness range, tensile strength, elongation, compression-set, and compression-deflection value. In addition, water absorption, shrinkage, ozone and aging resistance, brittleness temperature, flammability, thermal conductivity, sunlight, and weather-resistance qualifications have to be established in a specification for the closure strip.

The requirements made of the closure strip and the performance of commercially available closures are incorporated in Figure 9—"Technical Data on Closure Strips."

Referring to this figure, it can be seen when the solid rubber closure, in comparison to competitive material, would be more effective, long-lived, stable, more elastic, stronger, less permeable to water and air, and not easily distorted. Furthermore, this useful combination of properties could be predicted to be maintained over a rather wide range of temperatures (—30° to 40°F to 180° to 190°F, which covers an unusual range of climatic conditions).

In addition, the table brings out the solid rubber closure's ability to remain fairly inert to the deteriorating effects of atmosphere and normal installation conditions, with low heat conductivity, and offering a slow-burning, non-contributory element to the possibility of any building fire.

The demonstrated higher strength and greater toughness of the solid rubber closure permitted the use of its elastic qualities under conditions in which most cellular materials examined failed. Specifically, under the tests given, the solid rubber closure did not shrink, (to leave gaps in flashing) either before or after weathering; it did not absorb water, (it could be used to hold water out), did not lose its "rubberiness" (not taking a permanent set, it most nearly resumed its original shape, a quality very important in gaskets and other sealing members); and, solid rubber gave the long term service under severe conditions required of a closure (cellular closures exposed a large surface area of thin-walled material, making them more susceptible to deterioration).

Costing little more than the cellular rubber or cellular plastic closure, the study found, from field observation, the solid rubber closure's installed-cost often less than half as much as some jobs using cellular strips. Deteriorating anywhere from six months to three to four years, elasticity gone, and often falling out—many cellular closure jobs were forcing contractors to go back and mastic-seal the entire construction. Further, in his field travels, the author found the saving on job-site labor noteworthy (no special skills were required to install solid rubber closures and there was little opportunity for careless workmanship to produce a faulty seal). Erectors stated installation of the solid rubber closure could be made in any weather. And, they related that these gaskets were as tough as tire tread—they'd withstand rougher handling and still there would be leeway for dimensional variations in the corrugated panel, its framework, and surrounding flat-surfaced materials. Finally, only the solid rubber closure strip was found to recover from compression in the tests given and was observed assuming its original shape and dimensions after being distorted by fastening down on the job-site. If the closure gasket showed flow under pressure over the years, it would become a mere stuffing and a dubious seal. The solid rubber closure was clearly non-flowing and in all respects superior to the cellular strip in test and field observations.

Recommended Sample Specifications

In view of the uncertainty in the marketplace and manufacturers' varying claims for different materials as closure strips, it is felt that this study can be of greatest assistance to the building construction field, by formulating a guide for "a customer acceptance standard" or suggested "sample specification" for the closure strip. Where possible, to aid the specifications writer, as a representative of the ultimate consumer, the study will undertake using American Society for Testing and Materials' standards as references in its sample specifications.

Sample Specifications

The suggested specification, describing the qualities of the material found necessary to the strip's function as a closure, are on page 31.

Material Requirements.—The military standard (MIL-STD-417 (ORD) referred to in the sample specification (Paragraph 4.1) is that Federal Specification covering general purpose, solid, vulcanized rubber. Combined with ASTM-D-735, a key to the classification of elastomers for automotive applications, they define the test standards which the closure material should meet.

The first variation from the above established specification appears in the classification group *R-302.* The numbers 02 designate a compound having a minimum tensile strength of 200 pounds per square inch, which is below that considered under the specifications referred to above. (Actually, tensiles from 200 to 525-600 lbs. psi. can be made in "soft" rubber.) However, the author decided, when specifying the closure rubber, it was best to stick to the actual service required of the part. It seems to be a universally practiced fallacy to assign a wide range of tensile and elongation requirements, which have nothing to do with the performance expected of the part in service. Although tensile strength and elongation are valuable in development and control work in the rubber industry, it is felt that higher requirements in the closure material would give no added assurance of better performance. Properties such as weathering, recovery after compression, water absorption, etc. were felt to be much more important.

The hardness selected (in *R-302*, the number 3 stands for *30* Shore A Durometer hardness) is considered "soft" for vulcanized, molded rubber. Super-soft rubber can be made down to 10 Shore A durometer for certain irregularly corrugated shapes, but with some corresponding changes in performance and presumably increased cost (these might be classed R-102, R-203 etc.). In addition, the sample specification provides for a broad variation in weight of the material used in the closure (paragraph 4.4) to provide for differences in the specific gravity of the base elastomers used and their compounding.

The closure strip is assumed to be *black* in color. If colors other than black are desired, this should be specified. In addition, with color a non-black pigment will be substituted for *carbon black* reinforcement, (Paragraphs 4.2 and 4.6).

Dimensional Requirements.—All soft pliable materials (including flexible cellular plastics and elastomers) can be stretched. Stretching distorts the product throughout its entire length. Some tendency towards recovery from the distortion of stretching is also put into action by stretching. Thus, the closure's dimensional tolerances (Paragraph 5) are those that are absolutely necessary for the proper function of the part—taking into account this inherent pliability.

It should be noted that, in many instances, a rubber product is drawn on a standard drafting sheet designed for the metalworking industry. These sheets usually do list standard parts tolerances which apply to general machine work and do not necessarily apply to a rubber product.

Performance.—The compatability of the closure is mandatory. While cellular material was generally found unsuitable for thermoplastics, still, non-staining rubbers should also be used to protect against possible migration stains (Paragraphs 6.1 and 6.11) to the colorful organic finishes used to protect modern steel and aluminum panels.

Good weathering, sunlight, ozone, and oxidation resistance, having been proved an essential component of the closure system—specific tests are devoted to aging, brittleness, and weather resistance in this specification (paragraphs under 6.2).

Most important of these requirements, from the findings of this study, are the freezing-thawing cycle test (Paragraph 6.2) and the test for water absorption (Paragraph 6.3).

Of the remaining performance requirements, that of low compression set (Paragraph 6.5) is essential to the closure's primary function as a sealing gasket. The closure's insulation value (Paragraph 6.6) has a range of values given for material from very soft to medium soft rubbers. Also, a choice of flame-spread ratings (Paragraph 6.7)—a slow burning (Type I)—to an essentially self-extinguishing rubber (Type II) should be available.

Testing and Certification.—Paragraph 7. to 10. in the sample specification are simply added as suggested procedure in helping compliance with the specification.

Figure 10—Sample Engineering Material Specification for Solid Rubber Closure Strips

1. **SCOPE**—These specifications cover the requirements for a synthetic rubber material compounded of synthetic, natural, and/or reclaimed elastomers molded into closure or filler strips—where resistance to sunlight, weathering, oxidation and permanent deformation under load are prime essentials.

2. **USE**—The shapes, closure strips, etc., are used to weather-tight and structurally close openings in corrugated or ribbed panels at window heads, eaves, lower edge of siding and similar places.

3. **REFERENCES**—Any detailed drawings giving material size which accompany this specification or are specified on the purchase order shall be considered a part of this specification.

4. **MATERIAL REQUIREMENTS—**

4.1 Material shall comply to Federal Specifications MIL-STD-417 (ORD) or equivalent ASTM-D-735 (latest issue): Classification *R-302.*

4.2 A synthetic, soft, molded solid rubber material composed of synthetic or natural (and reclaimed rubbers). Reinforcement—*carbon black.*

4.3 *30(±5)* Shore A Durometer hardness—determination by ASTM-676 (latest issue).

4.4 Specific gravity shall be *0.97-1.25(+.05)* Determination by ASTM-D-792 (latest issue).

4.5 Ultimate elongation shall be 250% minimum—determination by ASTM-D-412 (latest issue) Die C.

4.6 Appearance:
The finished closures shall be uniform in construction and appearance and shall be non-porous, free of voids, weak sections, bubbles, foreign matter and other defects affecting serviceability, and *black* in color.

5. **DIMENSIONAL REQUIREMENTS—**

5.1 Length—The strip or shape shall be within ±⅛″ of the manufacturer's reported length.

5.2 Width and Thickness—The strip shall have the following tolerances in the cross sectioned dimensions:

½″ and under	±1/32″
Over ½″ to 1″ included	±3/64″
Over 1″ to 2″ included	±3/64″
Over 2″ to 3″ included	±3/32″
Over 3″	±1/8″

6. **PERFORMANCE**

6.1 Compatability—Material shall be compatible with and cause no deterioration to aluminum, galvanized surfaces, rigid polyvinyl chloride and fiberglass reinforced translucent plastic panels, etc.

6.11 Material shall not produce migration stains when in contact with standard organic finishes used by the purchaser as determined by ASTM-D-925 (latest issue) Method B.

6.2 Weathering and Aging—Material shall not show evidence of shrinkage, weight loss, break, crack, fissure or holes visible to naked eye after 15 years accelerated freezing, thawing cycle test.

6.21 When material has been heat aged for 70 hours at 158°F (ASTM-D-573) changes in material properties shall not exceed +10% in hardness, —20% in tensile, —25% in elongation.

6.22 Material shall not become brittle down to —40°F when tested in accordance with ASTM-D-746 (latest issue) Method B.

6.23 Material shall withstand prolonged exposure to sunlight, oxidation, and ozone. In weathering or accelerated ozone tests (ASTM-D-1149 or ASTM-D-1171) material shall equal Rating 2 to 3.

6.3 Water Absorption—Water absorption of the material shall be rated as negligible when rated according to Federal Test Method Standard 601, Method 6611.

6.4 Compression Deflection—A weight of 70± 10 lbs. per square inch shall be required to compress samples of the closure material 20% of its thickness (ASTM-D-575).

6.5 Compression Set—Material shall have a maximum compression set of 25% when temperature aged 22 hours at 158°F (ASTM-D-395, Method B.)

6.6 Thermal Insulation—The thermal conductivity ("K" value) of the closure material shall be 0.90-1.45 (BTU/sq. ft./Hr./°F/in.) when tested to ASTM-C-177.

6.7 Flammability—The rate of burning for Type I closures shall be less than 2.0 inches per minute, and the rate of burning for Type II closures shall be less than 0.50 inches per minute when tested in accordance with MIL-STD-417(ORD), Suffix M.

6.8 The closure shall be capable of continuous service up to maximum temperatures of 150°-190°F without softening and down to —40°F without becoming brittle.

7. **TESTING**—The manufacturer shall conduct tests on hardness, specific gravity and others he may deem necessary in order to certify conformance to this specification of all batches shipped.

8. CONFORMANCE CRITERIA—

8.1 From each batch, the number of tests for each requirement shall be as follows:

Number of Pieces in Batch	Minimum Number of Samples
800 and under	1
801 to 8,000	2
8,001 to 22,000	3
Over 22,000	5

8.2 Should any sample fail to meet the requirements, double the number of samples from the same batch shall be tested, in which case all of the additional samples shall meet the specification.

8.3 Since the selection of the samples is made by the supplier, he takes full responsibility that the samples selected are representative of the total batch.

9. CONFORMANCE CERTIFICATION—

9.1 The manufacturer shall submit a certification of conformance to this shipment to the extent that the product in each batch within that shipment have been tested by the manufacturer in accordance with Section 7 of this specification, and do conform to this specification. This certification shall be attached to the invoice in duplicate. Additional copies shall be furnished when specified on the purchase order. Deletions or exceptions to this requirement must have the written consent of the purchasing agent issuing the original order.

9.2 Inspection test reports for Section 7 shall be submitted in duplicate with each invoice. After an acceptable experience pattern has been determined by supplier test data, this provision may be relaxed by written agreement by supplier and the purchaser.

9.3 Upon request of the purchaser, the supplier shall be prepared to submit certified test reports that his product conforms to all requirements of these specifications.

10. **REMARKS**—All features of this material not specifically covered by this specification shall be of a quality equal to or exceeding that of the suppliers standard product.

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